HABIT AND INTELLIGENCE.

HABIT AND INTELLIGENCE.

HABIT AND INTELLIGENCE,

IN THEIR CONNEXION

WITH THE LAWS OF MATTER AND FORCE:

A SERIES OF SCIENTIFIC ESSAYS.

BY

JOSEPH JOHN MURPHY.

IN TWO VOLUMES.

VOL. I.

𝔏𝔬𝔫𝔡𝔬𝔫:

MACMILLAN AND CO.

1869.

PREFACE.

MANY of the speculations propounded in this work, as well as its entire plan, are original. It may consequently be of service to the reader to have it prefaced by a brief account of its purpose and of its leading ideas, written from the Author's point of view.

My chief purpose has been to state and to discuss what I regard as the special and characteristic principles of life. In the two chapters on the Chemistry and the Dynamics of Life, I have treated of the relation of life to ordinary matter and force : a relation which is now tolerably well understood. But the most important part of this work treats of those vital principles which belong to the inner domain of life itself, as distinguished from the principles which belong to the border-land where life comes into contact with inorganic matter and force. To that border-land belong such laws as those of nutrition and respiration : while to the inner domain of life belong the laws of organization and of mind.

In this inner domain of life, on which dynamics and chemistry have scarcely any light to throw, we find two principles which are, as I believe, co-extensive with life and peculiar to it : these are Habit and Intelligence.

I am compelled to use the word Habit in an unusually wide sense, though, as I think, a perfectly accurate one. I mean by habit, that law in virtue of which all the actions and the characters of living beings tend to repeat and to perpetuate

themselves, not only in the individual but in its offspring. This law is fundamental in both the unconscious and in the conscious life; or, to use commoner language, it is a fundamental law of life and mind. The law of the association of ideas, which is justly regarded as a fundamental law of mind, is only a case of the law of habit. I have made as full a statement as I have been able to do of the laws under which habits form, disappear, alter under altered circumstances, and vary spontaneously.

The word Intelligence scarcely needs definition, as I use it in its familiar sense. It will not be questioned by any one that intelligence is found in none but living beings; but it is not so obvious that intelligence is an attribute of all living beings, and co-extensive with life itself. When I speak of intelligence, however, I mean not only the conscious intelligence of the mind, but also the organizing intelligence which adapts the eye for seeing, the ear for hearing, and every other part of an organism for its work. The usual belief is, that the organizing intelligence and the mental intelligence are two distinct intelligences. I have stated the reasons for my belief that they are not distinct, but are two separate manifestations of the same intelligence, which is co-extensive with life, though it is for the most part unconscious, and only becomes fully conscious of itself in the brain of man.

Habit is in itself obviously an unintelligent principle. No intelligence is involved in the mere tendency to repeat an action or to perpetuate a character. But when the laws of Habit and of Intelligence have been stated, the question arises whether intelligence is an ultimate fact, incapable of being resolved into any other, or only a resultant from the laws of habit. This is by far the most important of all questions now under scientific discussion, and perhaps the most important that science can ever have to consider.

From the point of view adopted in this work, this question

divides itself into two: the one, concerning the unconscious intelligence that organizes the body; the other, concerning the conscious intelligence of mind.

The inquiry concerning the nature of the organizing intelligence involves an examination of that question of the origin of species which, since the publication of Darwin's great work on the subject, has probably attracted more interest than any other scientific question. I agree with Darwin in the belief that all species have been derived by descent with modification, probably from one, certainly from a few, original germs: and I further agree with him in attaching great importance to "natural selection among spontaneous variations" as part of the agency by which the modifications have been effected. But I altogether differ from him, in that I believe the wondrous facts of organic adaptation cannot have been produced by natural selection, or by any unintelligent agency whatever.

The latter part of the first volume is occupied with this inquiry into the origin of species and the nature of the organizing intelligence. The first part of the second volume is occupied with the parallel inquiry into the process of mental growth and development, and the nature of mental intelligence. As on the subject of organizing intelligence I have come to a conclusion which is fundamentally opposed to that of Darwin, so on this I have come to a conclusion which is fundamentally opposed to that of the dominant psychological school in this country: I mean that school which was founded, as I believe, by Hartley, and to which Mill, Bain, and Herbert Spencer belong. The characteristic point of their theory is, that they endeavour to account for the whole mental nature by the single principle of the association of ideas, or, as I call it, of mental habit. I maintain, on the contrary, that in all mental intelligence, as in organizing intelligence, there is an element not derived from habit, and not resolvable into any unintelligent force whatever.

In the chapters that follow the psychological ones, I have endeavoured to show how the science of history is capable of being elucidated by the same principles which have thrown so much light on the development of individual organisms and of organic species.

The subjects of the opening chapters are not in any obvious way connected with the laws of life. But life is a manifestation of force, and cannot be defined, or accurately thought of, except in relation to inorganic forces. For this reason I have commenced the work with some general statements on the subject of force and energy, and their relations to matter; and I have inserted a chapter on crystallization, for the purpose of showing the remarkable general contrast, with still more remarkable points of special resemblance, between the crystalline and the organic formative principles.

I have prefixed to this work an Introduction, on the subject of the historical tendency which all science is now so remarkably manifesting; and I have concluded it with three chapters containing some ideas on the classification, the history, and the logic, of the sciences.

I have throughout abstained as much as possible from technical language and technical modes of statement. It has been my aim to make the subjects treated of intelligible to any intelligent man who is willing to give the necessary attention, and to remove all difficulties except such as are inseparable from subjects which have not yet become familiar. I have endeavoured to give my authority for all important statements as to facts which are not matters of general notoriety; and when I have advanced any opinion of my own, I have advanced it as such.

In several places throughout this work, I have been brought to the borders of a region external to that which is usually regarded as the domain of science. Such subjects as the origin

of the universe, the origin of life, the nature of intelligence, and the nature and ground of the moral sense, suggest questions which, if they are to be answered at all, must be answered from data which are not to be found in the visible world. It is not from indifference to that class of questions, but rather from a conviction of their transcendent importance, that I have not entered on them in this work. I prefer to discuss them in a distinct work, which is already commenced, and which, unless a more appropriate title suggests itself to me, I purpose to call " The Scientific Bases of Faith."

OLD FORGE, DUNMURRY, CO. ANTRIM,
    April 8, 1869.

ERRATA.

P. 78, note, *for* square, prismatic *read* square-prismatic.
P. 81, note, *for* p. 77 *read* p. 71.

CONTENTS OF VOL. I.

INTRODUCTION.

CHAPTER I.

MATTER AND ENERGY.

CHAPTER II.

TRANSFORMATIONS OF ENERGY.

CHAPTER III.

STATIC AND KINETIC ENERGY.

CHAPTER IV.

PRIMARY FORCES.

CHAPTER V.

CHEMICAL ENERGIES.

CHAPTER VI.

THE MOTIVE POWERS OF THE UNIVERSE.

CHAPTER VII.

CRYSTALLIZATION.

CHAPTER VIII.

THE CHEMISTRY OF LIFE.

CHAPTER IX.

THE DYNAMICS OF LIFE.

CHAPTER X.

ORGANIZATION.

CHAPTER XI.

ORGANIC DEVELOPMENT.

CHAPTER XII.

THE DIRECTION OF DEVELOPMENT.

CHAPTER XIII.

ORGANIC SUBORDINATION.

CHAPTER XVI.

THE LAWS OF VARIATION.

CHAPTER XVII.

THE PROBLEM OF THE ORIGIN OF SPECIES.

CHAPTER XVIII.

DISTRIBUTION.

CHAPTER XXI.

EMBRYOLOGY.

CHAPTER XXII.

CLASSIFICATION.

CHAPTER XXIII.

THE CAUSES OF DEVELOPMENT.

CHAPTER XXIV.

NATURAL SELECTION.

CHAPTER XXV.

GENERAL REMARKS ON THE DEVELOPMENT OF SPECIES.

CHAPTER XXVI.

THE RATE OF VARIATION.

HABIT AND INTELLIGENCE,

IN THEIR CONNEXION WITH

THE LAWS OF MATTER AND FORCE.

INTRODUCTION.

IT is felt by all intelligent men, that there is a decided Intellectual character of this age. and even a profound difference between the intellectual tendencies of the present age and those of the last. It is felt that the point of view from which we regard the problems, both of science and of human life, is not the same as that of our forefathers of the last century. But, though this difference is universally felt, it is not easy to explain it in words, and it is quite impossible to sum it up so as to be intelligible in a single sentence.

Some of the most prominent characteristics of this age, however, and those perhaps the most important of all, are in no way peculiar to it, but are an inheritance from the last century. We inherit from our ancestors of the The rejection of authority is inherited from the last century. eighteenth century the habit of rejecting authority in matters of belief, or at least of demanding that authority shall justify itself; and, with this, the resolution to go to the sources of belief and knowledge for ourselves, and the conviction that the ultimate appeal in all questions whatever, whether speculative or practical, must be neither to authority nor to custom, but to intelligence. In a word, we inherit from the eighteenth century the belief that the intellect of man has a right to rule the world. This belief belongs, at least primarily, rather to morals and politics

Impor-
tance of
this to
scientific
progress.
than to science, but its importance to science is neverthe-less of the first magnitude. The first and most essential condition of scientific progress is the perfect independence of the intellect, and its freedom from all authority which cannot justify itself. Some sciences, in which the greatest progress has been made, have never been interfered with in their onward progress by any claims whatever on the part of authority. Such has been the case with mathe-matics and with chemistry. Other sciences, as astronomy, geology, and we may now add the sciences of life, of mind, and of language, have been trammelled in their infancy by the shackles of authority, and have been unable to make any great progress until these were cast away.

But in addition to this independence of authority, some of the dominant ideas of the present age in the realm of pure science have also been inherited from past centuries.

Idea of the
unity and
univer-
sality of
natural
law.
I speak of the belief that all existence is a domain of law, and that nothing is arbitrary : and of that sense of the mutual relation of all things which has passed into the current thought and speech of our time, and is expressed in such phrases as "the connexion of the sciences," and "the unity and universality of the laws of nature." These ideas, concerning the universality, the constancy, and the uniformity of natural laws, are not in any special sense characteristic of either this century or the last. They belong to science, and have been confirmed and strengthened with the progress of science. But they have taken a far stronger hold on the intellects, and I may add on the imaginations, of men in this age than they ever did before. This is a natural result of the real and great progress made by science in this age, not only in the same directions in which it was begun by former ages, but also in new directions, of which former ages only dreamed.

Newton's
law of gra-
vitation
The most important step ever taken, in the whole history of science, towards establishing this great doctrine of the unity of law throughout nature, was Newton's dis-covery of the law of universal gravitation : proving that the force which binds the planets in their orbits is the same as that which causes a stone to fall to the earth :

and thereby constituting physical astronomy as one vast application of the laws of force. By this magnificent generalization, it was shown that the laws of gravitation and of motion are the same throughout celestial space: and a variety of facts which have been ascertained since Newton's time, including the wonderful discoveries of spec- trum analysis, have established, with almost equal certainty, the identity of chemical laws throughout the universe. has shown the uni- formity of natural law through space.

While astronomy has shown the uniformity of natural laws throughout space, geology has shown the constancy of natural laws through time. The change which has transformed geology from a mere mass of conjectures into a true science, essentially consists in explaining geological phenomena by the same causes that we see in action at present, in the world as it is around us. The revo- lution in geology which is chiefly associated with the name of Lyell is an exact parallel to the revolution in astronomy which was effected by Newton. Before New- ton's time, the forces which govern the celestial motions were believed to be different in kind from those of which we see the effects on the earth: Newton showed them to be the same. Before Lyell's time, the facts of geology were usually referred to imaginary "catastrophes," pro- duced by causes of which it could only be said that they were unlike anything now in action: Lyell and his fellow- workers have shown how to account for them by the slow and continued action of those forces which we still see at work around us, in the air, in the waters, and in the volcanic fires.[1] Geology has shown the con- stancy of natural law through time.

- The latest of these great scientific generalizations is still in the same direction. It consists in the establishment of what is called the thermo-dynamic theory; that is to say, in proving that heat consists in molecular motion, and that the laws of heat are only a particular case of the laws of force. By this generalization, second in importance only The ther- mo-dyna- mic theory has shown the laws of force to be true on all scales.

[1] I shall, however, have to state in the chapter on "the Motive Powers of the Universe," my reasons for believing that some of these forces, though the same in kind, acted in former times with greater intensity than they do at present.

to Newton's law of gravitation, it has been shown that the laws of force and motion apply, not to masses of matter only, but also to atoms : it has been shown that those laws are true on all scales of magnitude, from a star to an atom.

Summary.   Briefly to recapitulate the substance of the last few paragraphs :—Astronomy has proved the unity of natural law through space, and geology through time; while the science of heat, and we may add those of light and electricity, have shown the same to be true on all scales.

This tendency to identify laws which at first appeared to have nothing in common, and thus to establish a wide and comprehensive unity of law, is not yet so conspicuous in the sciences of life and mind as in the inorganic sciences.

The same tendency is discernible in the sciences of life and mind.   I believe, however, that the only reason for this is the comparative backwardness of the sciences of life and mind, which is a necessary result of the greater complexity of their subject-matter. But even in them, there is a manifest tendency to break down apparent distinctions, and to establish real unity. We see this in the general abandonment of the old distinction between zoology and botany, and the merging of the two, for all philosophical purposes, in Biology, or the science of Life. We see the same in the general conviction that the science of Mind is a branch of the science of Life, or, at least, must be based on it. I hope, in this work, to do something towards proving unity of law among many of the phenomena of life and mind, which at first sight may appear to have nothing in common, by showing that the laws of Habit enter into all vital actions whatever. But the work which has already been done in astronomy by Newton and in geology by Lyell—the work, namely, of referring the most important facts of those sciences to known and intelligible laws—will not be done for the science of life, until the question of the origin of species is as much a solved problem as the problems of physical astronomy and of geology. The problems of physical astronomy have been solved by referring the planetary motions to the ordinary laws of force. The problems of geology are in process of solution by referring the facts of

geology, not to imaginary "catastrophes," but to the forces which we see at work in the world around us. And in like manner, as I believe, the question of the origin of species, which is the great question of the science of life, will be solved, and has already begun to be solved, by means of the ordinary laws of variation and development. I purpose to devote several chapters to this subject, and hope to throw on it a few rays of original light.

The question of the origin of species.

But the modern sense of the connexion and inter-dependence of all things goes very much deeper than the mere identification of physical laws. A most valuable habit has become general among men of mental cultivation, of regarding every subject, not as if it were alone and isolated, but in its connexion with other subjects.

Habit of regarding no subject as isolated.

Perhaps the best instance of this is one which I have already mentioned, namely, the altered way in which the questions of mental science are now regarded. Instead of beginning with the opposition of mind to matter, modern psychology begins with the connexion of the mental with the bodily nature. This modern sense of the connexion of all things is altogether opposed to the tendency of the scholastic period, which carried the love of system so far as to endeavour to map out the whole realm of knowledge into provinces separated from each other by hard and definite lines. I think we may safely affirm that if at any time the love of system were to become stronger than the love of truth, the effect would be the same. And if the attempt thus to define the province of every science by means of a rigid boundary were to be successful,— which of course is an impossible supposition,—it would condemn science to an immobility like that of the scholastic period.

Connexion of mental science with the science of life. This is contrasted with the scholastic tendency to isolate every science.

But a still more important effect of the modern sense of the mutual connexion of all things in the bonds of law is shown in the wider, and, as I believe, truer meaning with which we are beginning to use the word *science*. For generations past, science has been usually understood to mean mathematical and physical science only: yet they have no exclusive right to the name. All knowledge is

Wider meaning given to the word science than formerly.

scientific when it is reduced to principles, and the limita-
tion of the word to a particular class of subjects is due
merely to the fact, that for the last few centuries the
mathematical and physical sciences (including the science
of life) are those which have been cultivated with the
most success; so that in the imaginations of men they
have come to dwarf all others by comparison. But this
limited use of the word science was never universal;
the existence of the mental and moral sciences was never
forgotten; and we have now learned to use familiarly such
expressions as "the science of history" and "the science of
language." These are not mere chance phrases. They are
indications that a time will come, and is coming, when
every subject of thought which is capable of being syste-
matically reasoned about and understood will be regarded
as belonging to the domain of science, and when the use
of the word science in the sense of mathematics and
physics exclusively will be extinct; or, if it survive, will
survive as the relic of an extinct habit of thought: like
the word *mathematics* (τὰ μαθήματα), in the sense of
geometry and algebra only, or *learning* in the sense of mere
erudition. It is difficult to overrate the intellectual gain
of the increased wideness of view, or the moral gain of
the increased liberality of feeling, which may be hoped for
when all students whatever have thus learned to recognise
each other as fellow-workers.

Sciences of history and of language.

Benefit of this widened view of science.

I am of course aware that these remarks on the mutual
relation of the various sciences are very slight and super-
ficial; and I intend, towards the end of this work, to
devote a chapter to the classification of the sciences, in
which I shall state my ideas on the subject more com-
pletely and systematically.

Summary of preced-ing para-graphs.

In the foregoing paragraphs I have enumerated some of
the results of scientific progress which have become dis-
tinguishing intellectual characteristics of the present age.
They may be thus briefly summed up: In the first place,
we have a profounder comprehension than any previous
generation ever had, of the uniformity and constancy of
natural law, not only through universal space, but also

through geological time, and on all scales of magnitude, from a star to an atom. In the second place, there is a tendency among us to regard nothing as isolated, but, on the contrary, to think of everything in its relation with the universe of which it forms a part ; and, as a consequence of this, the rigid lines by which sciences were formerly separated one from the other are disappearing. And, in the third place, we are learning to extend scientific conceptions and scientific methods to many subjects, especially history and language, which formerly appeared to be outside the pale of scientific knowledge ; and we are gradually learning to regard all students of every branch of knowledge as fellow-workers in science.

But in all these we only carry forward the ideas of the last century to results of which the men of the last century scarcely dreamed ; and it is, I think, universally felt that the difference between our intellectual position and theirs is something profounder than this. Our characteristic difference from them consists, as I think, in the importance which we attach to the *historical method*. History, no doubt, was written with as much ability in the eighteenth century as it has been in the nineteenth. I believe that Gibbon's great work on the "Decline and Fall of the Roman Empire" has never been subsequently equalled for vastness of research, and for lucid arrangement of very perplexing materials. But that very work is one of the best instances of the difference of which I speak, between the conceptions of the last century and of this respecting history. It consists of an admirably arranged account of events as they passed before men's eyes, with clear, if somewhat slight, sketches of the more noticeable facts of society and government. But the real problem of the history,— the reason why the Roman Empire declined from its original strength and fell before its barbarian enemies,— so far from being solved, is scarcely stated. In the present age, no historian with the tenth part of Gibbon's powers would rest satisfied with doing what Gibbon did. I do not say that he would do the work better—this depends on individual powers, not on the systems of thought which

men learn from their contemporaries—but he would

attempt more: he would not be satisfied with describing the visible effects which constitute the events of history: he would endeavour to ascend from effects to causes, and to ascertain what the causes were which produced the decline and fall of the Roman Empire.[1] This method of regarding history, not as a mere succession of events,.but in the light of cause and effect, is essentially the scientific method: by it history has become scientific. It is not easy, nor is it very important, to determine how this modern and more profound conception of the problems of history grew up in men's minds. I do not think it was in any direct way due to conceptions derived from the study of physical science.

Thus history has become scientific, and, at the same time, science has become historical. Many scientific subjects admit of, and demand, an historical mode of treatment. This is especially true of geology, which, more than any other science, captivated the imaginations of the last generation, at least in this country. Every geological problem is an historical one; · its general formula may be stated thus: From an actual state of things, to ascertain the causes which have produced it. Astronomy, also, has become in some degree an historical science. I refer, of

course, to the Nebular theory, which aims, and, as I think, with a great degree of success, at giving a physical explanation of the origin of the solar system by the gradual condensation of a rotating nebula. I only mention this here as an instance, and a very remarkable one, of the tendency of science, at the present time, to occupy itself with historical questions, or questions of origin. I shall have more to say about it in the chapter on "the Motive Powers of the Universe."

The same tendency may to a great extent be asserted of the science of life, which, more than any other science, is captivating the imaginations of the present generation.

---

[1] This attempt has been made, I believe, with a great degree of success by Guizot, and by Mr. Finlay, the author of "The History of the Byzantine Empire."

The most interesting and important question in the science of life is, as I have already remarked, that of the Origin of Species; and this is an historical problem, or problem of origin, in exactly the same sense as the problems of geology, or that of the origin of the solar system. *The origin of species.*

All problems concerning the development of living beings are, by their definition, problems of origin: this is true alike of the development of the individual and of that of the species. The problems of geology, also, as we have seen, are problems of origin. In one word, both of these two classes of problems are historical. But there is an important difference between them. The problems of vital development are not only historical but genetic.[1] By this distinction I mean that the visible facts of geology are the results of causes acting from without and unconnected with each other; but the facts of organization and vital development are the results of causes which have their seat in the nature of the living organism itself. This distinction may perhaps not be quite intelligible without further explanation. In vital development, every stage is determined by that which has gone next before it. The egg of an insect gives origin to a worm-like larva; this is transformed into a chrysalis, and the chrysalis into a winged insect resembling the parent. These changes follow each other in a fixed order, which depends, not on any external agency, but on the mysterious laws of life belonging to the species; and the same laws determine the result of the developing process—whether, for instance, its ultimate product is to be a fly or a beetle. External agencies may hinder these formative laws from coming into action; that is to say, they may destroy the life of the larva, and so prevent the development of the mature form; but they cannot modify their action, except within very narrow limits; they cannot cause one species to be hatched out of the eggs of another. I shall have to show, in the chapters on the Origin of Species, how I believe this truth to be quite reconcilable with the theory of the origin of *The problems of vital development are genetic. Explanation of this word.* *History of vital development.*

---

[1] Genetic, from *genesis,* "original production."

Contrasted with geological history. species by a process of gradual change. In geological history, on the contrary, there is nothing in the slightest degree analogous to these fixed laws of development. There is no genetic process. Each event of the history is determined, not from within, as it is in vital development, but from without ; or, in other words, each event is determined, not by the event which has gone immediately before it, but by events the cause of which has no connexion with the series under investigation. Thus, for instance, let us suppose a stratum of limestone to be deposited in a shallow sea. What formation is to come next ? This is not in any way determined by the nature of the limestone ; it is determined by causes which act from without, and are in no way connected with the character of the strata already deposited. If the bed of the sea continues to subside about as fast as the limestone is deposited, strata of limestone may continue to succeed each other for an indefinite time. If, on the contrary, it is raised so as to convert the limestone stratum into dry land, an indefinite time may pass without any deposit whatever being formed over it. If the limestone continues to be covered by a shallow sea, while a change of the levels in a neighbouring continent causes a great and muddy river to flow into that sea, the mud will form a stratum lying over the limestone, and of a mineral character totally different from it : and if, what is a very probable occurrence, great spaces of very shallow water are kept free from mud by means of dense borders of aquatic vegetation, then, if the conditions of climate are favourable, these spaces will themselves be overgrown with vegetation, which, dying, will produce beds of a peaty substance : and subsequent geological changes may transform this into coal. And all these strata may be mechanically broken up and contorted by volcanic action, while at the same time they are chemically metamorphosed by the volcanic heat.

These examples will, I think, make my meaning clear when I speak of the difference between a genetic process and a simply historical one. A genetic process may be

defined as one which is governed by an internal law of development.

Now, the most characteristic studies, and the most *Genetic studies and methods are characteristic of this age.* characteristic methods, of this age, are the genetic ones. The science of life is studied genetically: the laws of the development of individual organisms are among the most important of the results yet attained by the science, and *Science of life.* the development of species is the most important of its problems. History is studied genetically: the historian *History.* does not think he has done his work unless he can trace the process by which one set of events, or one state of things among mankind, has given origin to another. The same is true of what may be called the secondary historical studies, such as the history of art and literature; and it is eminently true of the history of law, which study may *History of law.* be said without exaggeration to have attained to the rank of a science in the hands of Mr. Maine, whose work on Ancient Law shows an amount of research which is quite comparable to that of Gibbon, while at the same time it is illuminated by such a conception of true historical method as was never attained by any historian of the eighteenth century.

The same is true of the science of language. The *Science of language.* science of language is the history of language. Every language has been formed by a spontaneous genetic process, and the problems of the science consist in ascertaining the laws of the process. Little is known of the first origin of language, though it is not, perhaps, a totally insoluble mystery; but very much has been done towards determining the laws according to which one language is derived from another; and it does not derogate from the value of our knowledge of historical facts and genetic laws, if the first origin of the subject of the history is unknown.

It has become an axiom in the science of life that "development is the criterion of morphology;" which may *Development is the criterion of morphology.* be thus paraphrased, in untechnical language: "In order to know what a thing really is, we must know the process of its origin." This law is subject to some remarkable

exceptions, of which I shall have to speak when I come
to the subject of the Origin of Species; but I shall
endeavour to show that they are more apparent than
real : of its general truth there is no doubt whatever, and
no naturalist would regard the classification of any newly
discovered form as more than merely provisional, until he
had ascertained the mode of its development.

To know
what a
thing is,
we must
know its
origin.

Wide ap-
plicability
of this
axiom.

Artistic
criticism.

Now, this axiom, that development is the criterion of
morphology, or that, in order to know what a thing really
is, we must know the process of its origin,—this axiom,
I say, though it was first stated of living beings, is really
of much wider application ; it is applicable to all things
whatever which are produced by a process of development,
according to an internal genetic law.   It is, for instance,
impossible—impossible, I mean, in the sense of involving
a contradiction—really to understand a work of art, with-
out understanding the mind of the artist who produced it,
at least sufficiently to perceive his meaning and intention :
and this is identical with a rudimentary knowledge of the
mental process by which his work has been produced.
This is perhaps the clearest and best instance that can be
quoted from among the studies that arise out of human
history and the productions of the human mind ; but the
same is true, and is now generally recognised as true, of

Political
institu-
tions.

political institutions.   No institution, or, to use a wider
expression, no state of human society, can be really under-
stood unless its origin and its history are known ; and it
is possible for institutions to be exactly the same in form
and yet totally unlike in reality, if they are different in
origin.   Constitutional government, for instance, may be
one thing in a country where it has spontaneously grown,
and may be a totally different thing in another country
where its forms have been exactly imitated, but where it
has no historical root.

The recog-
nition of
this prin-
ciple is

These truths are now commonplaces : the saying that
" constitutions are not made, but grow," has become a
proverb.   The fact that this class of truths has become
commonplace among us, constitutes, as I think, the in-
tellectual peculiarity of the present century, and, I will

add, its superiority to the last. We have learned to apply what is most characteristic of this age. historical and genetic methods wherever they are applicable: and the importance of this is very great, not only in the study of science and of history, but in its practical application to human life. To use expressions which though familiar and hackneyed have a profound meaning, it has made political thought at once more conservative and more liberal.

The increased importance which we have learned to Conservatism. attach to historical methods has made political thought more conservative; for it is impossible that a student of history should despise the past. He may be a believer in indefinite progress; he may believe that the present is better than the past, and that the future will be better than the present. But he must recognise the truth, that no man or nation can "break with the past;"[1] that the present is the result and outgrowth of the past, and that the future will be the result and outgrowth of the present; and, however lightly he may esteem all that has been actually attained by the past and by the present, he must value them for the wealth of data and materials which they contain for the future. He may be boldly constructive; but he must be conservative, inasmuch as he cannot be destructive. The habit of mind which is produced by the historical and genetic study of the deeds and thoughts of men is opposed alike to revolutionary destruction and to what may be called revolutionary construction: I mean the direct application to practice of political and social theories deduced from à priori data, and independently of historical experience, according to the method which was characteristic of the period of the French Revolution—or perhaps we ought rather to say, of the period which prepared for that great revolution, and led up to it. The vast change which has come over the thoughts of cultivated men on this class of subjects may be gauged by comparing Bentham and Stuart Mill. Bentham with Stuart Mill: especially because, notwith-

[1] De Tocqueville, in his "France before the Revolution," has completely disproved the current notion that France, in the great Revolution, succeeded in breaking with the past.

standing this great difference, Stuart Mill regards himself
as fundamentally belonging to the same school of thought
with Bentham.   Between Bentham's treatment of political
questions and Mill's, there is all the contrast between revo-
lutionary construction and construction on an historical
basis.[1] In the present (1868) state of Europe, and espe-
cially of England, it is impossible to predict how many
experiments in revolutionary construction may be tried by
an uneducated democracy; but we are safe in asserting
that the influence of the cultivated classes, for the present
and for an indefinite time to come, has been secured on
the side of an historical way of regarding all political
questions, and against revolutionary construction as well
as revolutionary destruction.

Liberal-
ism.

At the same time, the new historical style of thought
tends to make men more tolerant and more liberal. His-
torical and genetic modes of studying the thoughts and
the actions of those who have gone before us have neces-
sarily the effect of producing the power, or if not the
power at least the desire, to appreciate the objects of
study.   We no longer think it enough to judge, however
justly, of deeds, or of laws, or of works of art.   We en-
deavour to account for them; to see them not only with
our own eyes, but with the eyes of their authors; to see
them, as it were, not only from without, but from within.
This appreciative sympathy with man is at the very root
of all that is best in that political and moral creed which
is rather vaguely called Liberalism; and it has, I believe,
acted powerfully, though in part unconsciously, in pro-
ducing the characteristically modern sense of the sacred-

Toleration
of all
opinions.

ness of mental freedom, and of the sinfulness of all
persecution of opinion, whether the opinion be religious
or any other.. For we have learned that belief is utterly
worthless, except when it is the product of free conviction.
We have learned that what is in form the same belief, or
the same creed, may be one thing if it is the result of free
conviction, and a totally different thing if it is the result

[1] See the Essays on Bentham and on Coleridge in Stuart Mill's Disser-
tations and Discussions.

of mere habit, or if it is imposed by external power; that
it may be more precious than life in the one case, and
more worthless than "salt which has lost its savour" in
the other. We have also learned to apply the same prin-
ciples to politics, and to recognise the truth that what are
in form the same institutions may be in reality quite dif-
ferent if they are imposed from without, from what they
would be if they were the spontaneous product of national
life. And in close connexion with this is the modern
sense of the *educative* value of political institutions and
political history; in other words, their value, not only in
the transaction of national business and in promoting
outward national prosperity, but also in their influence on
national character.

To conclude, I have in this Introduction briefly endea- Conclu-
voured to show that the chief and the most distinctive sion.
intellectual characteristic of this age consists in the pro-
minence given to historical and genetic methods of re-
search, which have made history scientific and science
historical: whence has arisen the conviction that we cannot
really understand anything unless we know its origin; and
whence we have also learned a more appreciative style of
artistic and moral criticism, a deeper distrust, dislike, and
dread of revolutionary methods, and a more intelligent
and profound love of both mental and political freedom.

CHAPTER I.

MATTER AND ENERGY.

IN this series of Essays I intend to proceed, according to the law both of nature and of thought, from the simple to the complex. Consequently, I shall treat of the laws of Matter before those of Life; and, in treating of the laws of Matter, I shall treat of those which are common to all matter, and to matter in all its actions, before the special laws of chemistry and crystallization.

It is not my purpose to write a regular treatise on elementary dynamics. In this and the following chapters I only intend to give a statement of some of the most important results of modern dynamical science, in a form that shall be at once theoretically complete and suitable for future reference. I shall employ as few mathematical terms as possible; but I fear it will be impossible to make the subject perfectly intelligible except to those who are acquainted with the fundamental conceptions of mathematics.

Four laws of conservation. There are in nature four, and only four, laws of conservation which we can assert to be absolutely and without exception true. These are the laws of the Conservation of Matter, of Momentum, of Rotation, and of Energy. These must be explained *seriatim.*

Conservation of matter. I. THE CONSERVATION OF MATTER.—*Matter can be neither produced nor destroyed by any process whatever.* This truth has been long known, and is familiar; but it is very far

from self-evident.   When wood or coal, for instance, is
burned, it appears to be destroyed; but we know that the
carbon which disappears combines with the oxygen of the
air to form carbonic acid gas.

II. THE CONSERVATION OF MOMENTUM.—*The total mo-* Conserva-
mentum of any body or system of bodies is unchangeable by tion of
any mutual action of its parts; or, in other words, *the* tum. momen-
motion of the centre of gravity of any body or system of
bodies is unchangeable by any mutual action of its parts.
That is to say, if the centre of gravity of any system of
bodies—as, for instance, the solar system—is at rest, no
mutual action of the bodies composing it can set it in
motion; and if it is in motion, no mutual action of the
bodies composing it can bring it to rest; nor can any such
action alter the motion of the centre of gravity, either in
direction or in velocity.

The case of an animal or a railway engine that moves
itself, is no exception to this law; for it is set in motion,
not by the action of its parts *on each other*, but by the
action of the whole *on the ground* which serves it as a
fulcrum.

III. THE CONSERVATION OF ROTATION.—*The total rota-* Conserva-
tion of any body or system of bodies is unchangeable by any tion of rotation.
mutual action of its parts.   That is to say, if any system of
bodies has no total rotation, no mutual action of the bodies
composing it can cause it to rotate; and if it is rotating, no
mutual action of the bodies composing it can bring it to
rest; nor can any such action alter the total amount of
rotatory motion, either in direction or in velocity.

The case of a rotatory steam-engine, or a horse in a mill,
is no exception to this law; for they are set in motion, not
by the action of their parts on each other, but by the
action of the whole on the framework or the ground that
serves as a fulcrum.

The total amount of rotation is thus estimated. Let Amount of
a line of indefinite length be drawn as an axis. It rotation, how esti-
may be drawn anywhere, and in any direction; it mated.

may be drawn either through, or outside of, the system of bodies in question; but for the purpose of forming a clear mental representation of the subject, let us suppose it drawn through the centre of gravity of the system of bodies, and at right angles to the principal plane of rotation. (For the solar system, this is nearly the same as drawing it in the line of the sun's axis of rotation.) From this axis, and at right angles to it, let a radius vector be drawn to every indefinitely small part of the bodies, all such parts being supposed of equal mass. Then *the algebraic sum of the products of the radii vectores into the tangential components of the velocities will be a constant quantity.* Or, to state the law in a slightly different form : *the algebraic sum of the areas swept over by the radii vectores will be equal for equal times.*

Conservation of areas, a synonymous term with conservation of rotation.

In allusion to this latter mode of statement, the law of the Conservation of Rotation is often called the law of the Conservation of Areas. What is still called Kepler's second law, namely, that the radius vector of every planet sweeps over equal areas in equal times, is the best known instance of the law of the conservation of rotation or of areas. In consequence of the perturbations which the mutual attractions of the planets produce in each other's motions, Kepler's Second Law is not absolutely true of any one planet; but it would be so, if the solar system consisted only of the sun and a single planet.

Conservation of energy.

IV. THE CONSERVATION OF ENERGY. — *Energy*, like Matter, *can be neither produced nor destroyed by any process whatever.* Or, in other words : *Whatever quantity of energy has been expended in doing work, reappears as energy.*

The conservation of energy, like the conservation of matter, is contrary to appearance. But energy, like matter,

Transformation of energy.

when it appears to be destroyed is really transformed. For instance, when a railway train is stopped by the action of the break, or when a cannon-ball sticks fast in a bank of earth, the energy of motion which has disappeared is transformed into heat. The heat that is produced by mechanical action, such as friction or collision, is not a

mere concomitant of the mechanical action, as was for-
merly believed; it is energy of motion, which, as we have
every reason to believe, has been transferred from the mass
to the molecules.

The conservation of energy was formerly, and is fre-
quently still, called the conservation of force. But, as I
shall have to explain, the word force has another meaning;
and Professor Rankine has proposed the word energy in
this sense.

In order to explain what is meant by the conservation
of energy, I must begin by defining the words momentum,
force, energy, and work.

The momentum of a moving body is the product of its Defini-
mass into its velocity. tions of
Momen-
Force is that which produces motion. Equal forces are tum,
those which, when acting through equal times, produce Force,
equal momenta. It follows from this that equal forces,
acting in opposite directions, neutralize each other; as, for
instance, two weights on the opposite ends of a lever
which balance each other, so as to prevent either from
descending.

Energy is that which does work. Equal quantities of Energy,
energy are those which are capable of doing equal quan-
tities of work: or, in other words, equal quantities of
energy are those which are capable of overcoming equal
resistances through equal spaces. When for instance a
weight is raised, a quantity of energy is expended and
transformed, proportionate to the product of the weight
into the height through which it has been raised.

Work is thus correlative with energy, and work may be and Work.
defined as *resistance overcome*.

Energy is not the same as Force. All energy has its
origin in force, but force cannot pass into energy unless it
is at liberty to act. Thus, gravity is a force, but no energy
is due to it unless it has space through which it can act by
causing bodies to fall: and *the quantity of energy is pro-* Measure of
portionate to the gravitative force, multiplied into the space energy.
through which that force acts. For instance: the weight, or
gravitative force, of the water of the ocean causes it to

press on its bed with a pressure proportionate to the depth; but no energy is due to this pressure, because there is no space through which the water can fall. But to the position of the water in a mill-pond a quantity of energy is due, proportionate to the weight of the water multiplied into the height through which it may be allowed to fall.

Potential and actual energy. Energy which is thus due to the possible action of a primary force[1] that is not actually in action, is called potential energy. When energy ceases to be potential, it becomes actual. The potential energy of a raised weight is proportionate, as I have just explained, to its mass multiplied into the height through which it is *capable of falling;* the actual energy of a moving body is proportionate to its mass multiplied into the height through which it *must have fallen* in order to acquire its velocity.

Their mutual transformation in the motion of a pendulum. Potential and actual energy are in constant process of transformation, the one into the other. The simplest case of this is the oscillation of a pendulum. During the descent of the pendulum-bob, a portion of energy proportionate to the vertical height through which it descends is transformed into the actual energy, or energy of motion, due to its velocity at the lowest point of its stroke; and when the pendulum-bob rises to its former height on the opposite side, this actual energy is transformed back into potential energy again. Supposing no energy to be wasted by friction, the pendulum-bob will always rise to exactly the same height at the ends of the stroke, and will always attain to exactly the same velocity in the middle: as required by the law of the conservation of energy, no energy will be either lost or gained. This condition of the total absence of friction is not perfectly attainable in our experiments, but we can make a very near approximation to it. As already stated, the energy wasted in friction is not destroyed, but transformed into heat. This transformation of energy thus effected in the oscillation of the pendulum is a simple type on a small scale of what is constantly going on in endless complexity and on the vastest scale throughout the entire universe.

[1] For the meaning of the expression *primary force* see p. 32.

Energy, like Matter, is measurable by quantity; [1] and, Energy
like matter, energy is capable of being stored. A mill- may be
pond is a means of storing energy; and a still better in- stored:
stance, though exactly the same in principle, is Sir William instance
Armstrong's hydraulic accumulator. This is a contrivance of the
for enabling a small steam-engine or other source of motive accumu-
power to do very heavy work for a short period of time. lator.
It consists of a forcing-pump, through the action of which,
by hydraulic pressure, the motive power of the steam-
engine raises a very heavy weight. An amount of poten-
tial energy, proportionate to the weight multiplied into the
height through which it is raised, is thus accumulated;
and when it is desired to give out energy and do work, this
is done by letting the weight descend and using its pres-
sure as motive power. The steam-engine is able to raise
the weight but slowly, but the weight is able to descend
rapidly, so that the potential energy which is stored up
through a comparatively long time may be given out in a
short time, and employed in work that requires a great
expenditure of energy in a short time, as, for instance, in
raising great weights.

From the law that energy can be neither produced nor
destroyed, follows, to use the common expression, the *im*- Perpetual
possibility of a perpetual motion. But this is not a good motion:
expression: in any obvious meaning of the words it would
be much nearer the truth to say that the law that energy
cannot be destroyed makes perpetual motion *necessary;*
and this is rigidly true if, as we cannot doubt, heat is a
form of motion. What is meant, however, by the impos- in what
sibility of a perpetual motion, is the *impossibility of* sense
an inexhaustible source of energy. It is impossible, for sible.,

---

[1] It may be thought that whatever is measurable at all must be
measurable by quantity. This, however, is not the case. Heat, for instance,
is measurable by quantity; equal quantities of heat will melt equal quan-
tities of ice. But temperature is measurable, not by quantity, but by
degree: *quantity of temperature* would be an unmeaning expression. So of
force; equal forces will balance, and will be balanced by, equal weights.
We say, for instance, that the force of atmospheric pressure, as measured
by the height of the column of mercury that balances it in the barometer,
varies from hour to hour; but the *quantity* of this force would be an
unmeaning expression.

instance, to construct a machine that can do work without parting with energy; and when the energy is all parted with, any machine whatever must necessarily cease to do any more work unless a fresh supply of energy is brought in from without. It is impossible to make a water-mill work without a constantly renewed supply of water, or to make a steam-engine work without a constantly renewed supply of fuel. Every one who understands mechanics knows that any such inexhaustible source of energy is impossible by means of merely mechanical arrangements; but it is equally true, though not perhaps quite so evident, that it is impossible by means of any arrangement of thermal, electric, or chemical forces.

NOTE.

FORCE AND ENERGY.

In the present note I purpose to add some further explanations and illustrations of the relation between Force and Energy, in order to assist the formation of clear conceptions on a subject that lies at the very root of physical science, and yet is often insufficiently understood.

Faraday's question,

Some years ago, the greatest purely experimental philosopher then living, and perhaps the greatest that has ever lived—I mean, of course, Michael Faraday—surprised not only scientific men but thinking and reading men generally, with the question:

as to the law of conservation.

How can the law of the Conservation of Force, according to which force is *invariable*, be reconciled with the law that the force of gravity *varies* inversely as the square of the distance?

Answer.

This question really perplexed Faraday's mind. But the difficulty arises from a purely verbal confusion. Speak of the Conservation of Energy instead of the Conservation of Force, and the apparent contradiction disappears. There is no contradiction between the law of the conservation of *energy*, and the law that gravitative *force* varies in the ratio of the inverse square of the distance.

The same distinction solves another question that perplexed Faraday's
Faraday. Gravitation is a force; electricity is a force; all forces question
as to
whatever are correlated; what is the special correlation between gravity
these two? Faraday devised experiments in order to discover and elec-
some such special correlation, but did not obtain any result. tricity.

The answer to the question is, however, very simple, and easy Answer.
to illustrate by experiment. Gravity is a *force*, and electricity
is a *form of energy:* the force of gravity may produce the energy
of motion of a falling body, and part of that energy of motion
may be transformed into the energy of electricity. If the weight
of falling water works a water-mill, and this works an electrical
machine and produces electricity from it, there is a perfect ex-
perimental illustration of the relation between gravitation and
electricity; for the electricity, like the heat, which is produced
by friction, is not a mere concomitant of the friction; it is a
part of the energy of motion, which has been transformed.

The same verbal ambiguity was at the root of the controversy, Contro-
now long ago settled, as to the measure of the force of a moving versy as
to the
body;—whether the force was proportionate to the mass mul- measure
tiplied simply into the velocity, or to the mass multiplied into of Force.
the square of the velocity. All are now agreed that the *energy* Energy of
of motion, to which the power of doing work is due, is propor- motion
tionate to the mass multiplied into the square of the velocity.
For instance: supposing the mass, or weight, of a projectile to
be given, its power of penetrating is proportionate to the square
of the velocity. But the *force* of a moving body is proportionate
to the mass multiplied simply into the velocity: in other words,
to its momentum. The proof of the last statement is this. As and mo-
already stated, equal *forces* acting in opposite directions neutralize mentum.
each other. Now, it is found by experiment as well as by theory,
that equal *momenta* in opposite directions neutralize each other;
that is to say, two bodies coming into collision with equal
momenta in opposite directions (supposing of course that they
are of lead or some other inelastic substance, so as not to re-
bound) will destroy each other's momenta and bring each other
to rest.

In such a case, the energy of motion that disappears is of
course transformed into heat.

It follows from the statements given above as to the measures
of momentum and of energy of motion, that if two bodies are
in motion whereof one has a hundred times the velocity of the

other and only a hundredth of its mass, their momenta will be
equal; but the smaller one will have a hundred times as much
energy of motion as the larger. For instance: suppose a cannon
to be placed on a railway smooth enough to enable it to recoil
without any sensible friction; and suppose a projectile of one
hundredth of the weight of the cannon to be fired from it, the
law of the conservation of momentum makes it necessary that
the position of the common centre of gravity of the cannon and
the projectile should be unchanged; consequently the velocity
of each will be inversely as its mass, and the cannon will recoil
with a velocity equal to a hundredth of that of the projectile.
Their momenta will consequently be equal; but the energy
of motion of the projectile will be a hundred times that of
the cannon.

Of course the quantity of heat, or of any other form of
energy that is produced when motion disappears, is due, not
to the momentum, but to the energy of motion; not to the
velocity simply, but to the square of the velocity.

Their difference illustrated.

CHAPTER II.

TRANSFORMATIONS OF ENERGY.

A S already stated, the energy of motion of a moving body is due to its mass multiplied into the height from which it must have fallen in order to acquire its velocity.[1] And also, its energy of motion is proportionate to its mass multiplied into the square of its velocity. Energy of motion is thus definitely measurable by quantity. *Energy of motion,*

Heat is also definitely measurable by quantity. Equal quantities of heat are those which equally increase the temperature of equal quantities of the same substance. For instance: equal quantities of heat will raise the temperature of equal quantities of water by one degree of the thermometer. *and heat, are measurable by quantity. Measure of heat.*

Now, it is found by experiment that *equal quantities of energy of motion are capable of transformation into equal quantities of heat;* and, conversely, equal quantities of heat are capable of transformation into equal quantities of energy of motion. This is called the law of the dynamical equivalent of heat. Its numerical statement is, that the energy which is due to the descent of one pound of weight of any substance whatever through 772 feet of height is capable of transformation into so much heat as will raise the temperature of one pound of water by 1° Fahr.[2] This, *Dynamical equivalent of heat.*

[1] See page 20.
[2] Tyndall on Heat as a Mode of Motion, p. 40. It would take a fall through 1,390 feet to raise the temperature of a pound of water by 1° Centigrade.

as might be expected, is alike true, whatever be the process by which the transformation of the energy of motion into the heat is effected : whether it is by collision, as when a projectile flashes fire against the target ;[1] or by friction, which may perhaps be regarded as consisting of an infinite number of molecular collisions ; or, as in one of the experiments by which Professor Joule ascertained this law, by transforming energy of motion into electricity, and this into heat ; or by the compression of air.

It is scarcely necessary to say, that when all the energy of motion of a moving body is transformed into heat, the body ceases to move.

Heat is molecular motion.   This fact, that whatever quantity of energy of motion disappears is represented by an equivalent quantity of heat, makes it highly probable that heat is really motion, the motion of the molecules of the heated substance ; so that the *transformation* of energy of motion into heat is really the *transfer* of the energy of motion from the *mass* of the body that ceases to move to the *molecules* of the bodies that become heated. In a word, *heat is molecular motion.* I do not say that the facts already mentioned are sufficient to prove this : I admit that they only suggest it. But this theory is confirmed by all that we have learned of the action of gases under pressure ; and the dynamical theory of heat is now as well established as the undulatory theory of light.

All matter is perfectly elastic.   I may here remark, though it is a digression, that the fact of the apparently lost energy of motion being transformed into heat, or molecular motion, proves the very important and previously unknown truth, that *all matter is perfectly elastic.* If two balls of a highly elastic substance, such as ivory, come into collision, they rebound with great force, and very little of their energy of motion disappears. But if two balls of lead, or of any other almost inelastic substance, come into collision, they rebound with

---

[1] "Mr. Fairbairn informs me that in the experiments at Shoeburyness it is a common thing to see a flash of light, even in broad day, when the ball strikes the target." (Tyndall on Heat as a Mode of Motion, p. 437.)

very little force, and nearly all their energy of motion
disappears. We now, however, know that the energy of
motion which is lost by the masses is transferred to the
molecules, being transformed into heat; so that the
elasticity in which the masses are deficient is shown to
belong to the molecules. Thus, what appears to be
inelasticity is really a form of elasticity.

When energy of motion disappears, it is generally trans- Motion
formed into heat, but under special circumstances it is formed
transformed into electricity. This is done by the common into elec
electrical machine, in which, by a suitable arrangement, tricity.
a large part of the energy of motion that is usually trans-
formed by friction into heat is transformed into electricity
instead. The law on this subject appears to be, that
similar substances rubbing against each other produce
heat, but dissimilar ones produce electricity; and the more
unlike the substances are to each other, the more of the
energy of motion that disappears is transformed into
electricity, and the less into heat.[1]

In the electrical machine, artificial means are used to
retain the electricity when it is produced. But when these
are not used, the electricity nearly always escapes as soon
as produced, and, in escaping, is transformed into heat.
We may consequently lay it down as a law which is prac-
tically true throughout nature, that when energy of motion
seems to be lost, it is really transformed into heat.

Energy of motion is also transformed into electricity by
a totally different process in the magneto-electric machine.

The nature of electricity is not nearly so well understood
as that of heat and light. I state some experiments and
reasonings bearing on the subject in a note to Chapter III.

Equal quantities of energy of motion, as already stated, Quantita-
are capable of transformation into equal quantities of valence of
heat; and equal quantities of energy of motion are capa- all forms
ble of transformation also into equal quantities of electric of energy.
energy.[2] Equal quantities of electric energy and of heat

---

[1] Grove on the Correlation of Physical Forces.

[2] I say that equal quantities of heat or of energy of motion are capable
of transformation into equal quantities, not of *electricity*, but of *electric*

are also capable of transformation the one into the other. This relation of *quantitative equivalence* must indeed necessarily exist between all forms of energy, in consequence of the law of the conservation of energy, by which energy is unalterable in quantity through all its transformations : it may be transformed, but its quantity can be neither increased nor diminished.

Radiation of heat.   One of the most remarkable properties of heat is its property of transferring itself from one body to another, across vacant space, by radiation. But when heat assumes the radiant form, as it does, for instance, when on its way from the sun to the earth, it obeys laws totally different from those which are properly the laws of heat—it obeys laws which are, so far as experiment can inform us, perfectly identical with those of light—it becomes capable of reflec-

Radiant heat, light, and the actinic rays. tion, refraction, and polarization. Radiant heat is thus a distinct form of energy from heat of temperature, or what is properly called heat ; while, on the other hand, it differs from light only as two differently coloured rays of light differ from each other. And the same is true of the invisible chemical rays of the solar spectrum, or what have been called the actinic rays ; they differ from light or from radiant heat only as two differently coloured rays of light differ from

---

energy ; for the quantity of heat, or of any other form of energy into which the electricity of an electrised body is capable of being transformed, is not simply proportional to what electricians call the *quantity* of the electricity wherewith it is charged, but to the *quantity* of the electricity multiplied into its *tension :* or, what comes to the same thing, supposing the extent of electrised surface to be given, the quantity of heat into which the electricity is capable of being transformed is proportional, not to the quantity, but to the square of the quantity. This may be compared with the law that, supposing the mass of a moving body to be given, the energy due to its motion is proportionate, not to the velocity, but to the square of the velocity. (See p. 24.)

The definition of electric intensity and of quantity of electricity is, that if an electrised ball of metal is brought into contact with an unelectrised one of the same size, the electricity will spread over both ; and when it has so spread, its *quantity* is said to be unchanged, but its *intensity* reduced to one-half. In this diminution of intensity there is a transformation of energy into heat. (See De La Rive's Electricity, English translation, vol. ii. p. 219, *et seq.*)

each other.[1]   Light, radiant heat, and the actinic rays, all
beyond any reasonable doubt consist of vibrations in a
medium that fills all space.   They are consequently to be
classed as one and the same form of energy, which I   classed
intend in future to call *radiance*.   The fact that only   together as
radiance.
some of the rays of the sun's radiance are luminous
depends not so much on their own nature as on the
properties of the nervous apparatus by which we see ;
and it is not at all improbable that to some animals rays
may be luminous—that is to say, may give the sensation
of light—which are obscure to us.[2]

When radiance is absorbed, it is transformed back into   Absorp-
heat ; as, for instance, when the sun's radiance warms an   radiance.
tion of
object on which it falls.   Radiation is the transformation
of heat into radiance ; absorption is the transformation of
radiance back into heat.

If radiance is a form of energy, concerning which there
can be no doubt whatever, every ray must have some
energy.   The energy of the luminous and actinic rays, how-
ever, when separated from the obscure ones, is very small,
as shown by their very small heating power.   The rays of
the moon are usually believed to have no heating power at
all, but Professor Piazzi Smith found that the heat of the   Heating
moonbeams on the Peak of Teneriffe, as measured by the   power of
moon-
thermo-electric multiplier, are equal in heating power to a   beams.
candle at a distance of twenty-six feet.[3]

I have now enumerated the principal kinds of actual
energy, namely, Energy of Motion, Heat, Electricity, and

---

[1] This is not quite accurate, for all rays are heating rays : if it were not
so, there would be radiance incapable of transformation into heat, and we
know that all energy is capable of transformation into heat.   But the
maxima of heating power, of illuminating power, and of chemical power,
occur in different rays.

[2] It has been suggested that the eyes of cats and other nocturnal animals
are more sensitive than ours to the highly refrangible rays which abound
in twilight.

[3] Piazzi Smith's Teneriffe, p. 212.   Piazzi Smith found that when the
moon was at an altitude of about 42° and the weather perfectly serene, its
heating power was equal to about a third of that of a candle fifteen feet off.
By the law of the inverse square, the heating power of a candle at fifteen
feet is three times what it is at twenty-six feet.

Radiance; and shall proceed to enumerate their principal modes of transformation.

Trans-
formation
of motion
into heat,
 I. Motion is directly transformed into heat by collision and friction, and also by the compression of air or any other gas or vapour.

and the
converse :
 Conversely, heat is transformed into motion by the expansion of gases and vapours under pressure, as in the steam-engine. It is experimentally proved that when any gas or vapour expands into vacant space, so as to do no work in expanding, its temperature is not altered by expanding; but when it expands in such a way as to do work by expanding (as steam does in the cylinder of a steam-engine), its temperature falls; and the heat that has disappeared is the equivalent of the work done.

Motion
into elec-
tricity,
 II. Motion is transformed into electricity by the common electric machine, and also by the magneto-electric machine.

and the
converse :
 Conversely, the energy of electricity is transformed into that of motion, when a body is moved by electric attraction or repulsion.

Electricity
into heat,
 III. Electricity is transformed into heat, when it is discharged under such circumstances as to prevent work from being done in any other way. This takes place in the formation of the electric spark.

and the
converse :
 Conversely, heat is transformed into electricity, and an electric current is produced, when two substances that conduct heat unequally are placed in contact, and heat applied at the point of contact. Such currents are called thermo-electric currents.

Heat into
radiance,
and the
converse.
 IV. Heat is transformed into radiance by radiation.

 And, conversely, radiance is transformed into heat by absorption.

 We have seen that by the law of the conservation of energy, the energy that does work always reappears as energy. This is self-evident when the resistance overcome in doing the work consists in raising a weight; the energy reappears as the potential energy due to the raised weight, and is ready to be converted into actual energy again when the weight falls. When the resistance over-

come consists in friction, we now know that the work
done is represented by heat or electricity. But when the
work done is of such a nature as to alter the state of the No excep-
body on which work is done, as for instance in sawing tion to the
wood or grinding corn, it might be supposed that the ance of the
energy that has done the work is represented by the work energy
done, and will not reappear as energy. This, however, is done work.
not the case; it is transformed into heat or electricity, just
as when the work done consists simply in overcoming
friction.

In speaking of the potential energy of gravitation, I
have remarked that a force cannot produce energy, if, like
the pressure of the ocean on its bed, it is so placed that it
cannot cause motion. But the force that is overcome in
sawing wood or grinding corn—namely, the force of solid
cohesion—is a force that cannot produce energy, not for Forces that
want of room to act, but because it is not its nature to do so. cannot
produce
It is *mere* resistance; and it would be an improvement in energy.
our scientific language if the word *force* were confined to
forces that can produce motion, and the word *strength*
always applied to forces of mere resistance.

Strength is measured by the force required to overcome Measure of
it: the strength of materials, for instance, is measured by strength.
the weights needed to break or crush the materials.

CHAPTER III.

STATIC AND KINETIC ENERGY.

I HAVE defined potential energy as " energy due to the possible action of a primary force that is not actually in action." [1]

Primary forces.

By primary forces I mean forces which do not originate in any other forces, but are to be referred directly to the laws of nature. Gravity and chemical affinity are primary forces : matter has been created with them. But the attractive and repulsive forces of electricity and magnetism are not primary forces, because the electrised and magnetised states of matter are not parts of its original constitution. Matter may acquire and may lose electricity or magnetism, but it cannot acquire and cannot lose weight.

Electric and magnetic forces not primary.

Static and kinetic energy.

Energy is either potential or actual.[1] Energy is also either static or kinetic.[2] All potential energy is static ; but actual energy may become static.

Strained elasticity.

The simplest case of static actual energy is that of strained elasticity. If work is done, for instance, by bending a spring or stretching a piece of india-rubber, the work done is represented by the static actual energy due to the strained elasticity ; and when the spring or india-rubber starts back to its original shape, it parts with the energy, which then assumes some other form. A spring

---

[1] See p. 20.

[2] Kinetic, from κινέω, to move. Professor Rankine uses the terms potential and actual energy where I speak of static and kinetic. He consequently classes as a kind of potential energy what I call static actual energy. The difference is only one of words.

that has just been suddenly released from tension, will,
if it is elastic enough, vibrate rapidly for some time;
the energy of motion due to its vibrations has been pro-
duced by transforming the static energy that was due
to the straining of its elasticity: and the vibrations
continue until their motion is carried away by being
transferred to the air and to the substances surrounding
the spring.

So, when the string of a musical instrument is drawn Vibrating
to one side, the energy that has done work in drawing it strings.
is transformed into the energy due to its tension : and as
it vibrates, the energy vibrates back and forward between
the static and kinetic forms : being static at the ex-
tremities of the vibration, where the string has no velocity,
and kinetic in the middle, where its velocity is at the
greatest. This is an exactly parallel case to that of the
oscillatory transformation of energy between the potential
and actual forms in the motion of the pendulum :[1] for
the principle of the transformation is not affected by the
fact that, in the case of the pendulum, the energy at the
extremity of the stroke assumes the static potential form,
and in the case of the vibrating string it assumes the
static actual form.

Energy of motion, heat, and radiance are all kinetic
forms of energy : and so is current, or voltaic, electricity.
Static electricity is a form of static actual energy : and in
a note to this chapter I shall give reasons for believing
that, as heat consists in molecular motion, so magnetism,
and probably electricity, consist in the straining of pecu-
liar molecular tensions.

But in the chapters on chemical energies and on vital
energy I shall have to describe forms of static actual
energy of which we cannot give any such explanation, or
indeed any explanation whatever.

It ought to be mentioned here, that it is possible for Trans-
one form of static energy to be transformed into another of static
without passing through any intermediate kinetic state. energy.
For instance, the water that descends in the buckets of an

D

old-fashioned water-wheel (not a turbine) moves with so
small a velocity, that its energy of motion may be regarded
as nothing in comparison with the amount of energy of
motion that it would attain if it were permitted to fall
unobstructed. If, then, the water-wheel is employed in
raising weights, the potential energy given out by the
descending water is transformed into the potential energy
of the raised weights, without any intermediate formation
of energy of motion. Of course the same kind of trans-
formation is possible between the static energy of a raised
weight and the static energy of a compressed spring.

NOTE.

ELECTRIC AND MAGNETIC ENERGY.

In this note I intend to give my reasons for believing that
electricity and magnetism consist in the straining of molecular
elasticities.

Electro-
dynamic
induction.

Let two conducting wires, A and B, be placed alongside of
each other : or, what is better in many experiments, twisted
together into a hollow spiral, but kept from metallic contact by

Experi-
ment I.

some non-conducting substance. Let an electric current be
allowed to flow along A for an appreciable time, and then cut
off: on the current beginning to flow along A, a momentary
current flows along B in the *opposite* direction to that along A ;

Experi-
ment II.

and on the current ceasing to flow along A, another momentary
current flows along B in the *same* direction as that along A.[1]

Explana-
tion.

The most probable interpretation of these facts is, that at the
moment when the current begins to flow along A, the molecules
of B are thrown into a state of elastic tension: the act of the
molecules of B, in assuming the state of tension, constitutes the
first current along B ; and the second current (which, as stated
above, is in the opposite direction to the first) is constituted by
the act of the molecules of B, on the cessation of the current
along A, falling back into their normal state.

[1] De la Rive on Electricity, English translation, vol. i. p. 355.

If this interpretation is true, (and it appears to me the only possible one,) it follows that during the flow of the current of A, and between the flow of the two momentary currents of B, a definite quantity of energy has become static in B, due to the tension of its molecules. And, as ought to be the case on this hypothesis, the longer are the wires, the greater will be the force of the current of B ;[1] for, supposing the force of the tension to be given, the quantity of energy due to the tension will obviously be in proportion to the length of the wire. In other words, the greater is the length of wire that is thrown into a state of tension, the greater will be the quantity of energy due to its tension.

But as no process can either create or destroy energy, the energy that has become static in B must have come from somewhere ; and its only assignable source is the current of A. This is corroborated by the following facts :—

The current of A is the *inducing* current, and those of B the *induced* currents. It is possible to leave out B, and to obtain the induced currents in A : in other words, it is possible to obtain the induced currents in the same wire with the inducing current. Let A be sufficiently long, and let B be left out ; let Experi-
the current along A be stopped by breaking contact suddenly; in ment III.
the act of breaking contact there will be a momentary increase of the force of the current, producing a spark. This increase of the current is evidently the same as the current that would have been induced in B, had B been there, *in the same direction* as that of A. The two currents, the inducing and the induced, flow for the moment along the same wire and in the same direction, and the spark is due to the *sum* of their effects.

But the current induced in B, at the commencement of that of A, is *opposite in direction* to that of A : so that if the inducing and the induced currents can be caused to exist at once in the same wire, the resultant current will be due to their *difference.* This may be experimentally shown. If B is left out, and A long Experi-
enough, the current will be sensibly diminished in force at the ment IV.
moment of its commencing to flow along A.[2]

[1] De la Rive on Electricity, English translation, vol. i. p. 358. These facts were discovered by Faraday, who at first gave an explanation of them with which mine is substantially identical. He called the state of tension into which wire B is thrown the *electro-tonic state.* He afterwards, however, changed his opinion on grounds which I do not understand.
[2] Ibid. pp. 359, 360.

Explana-
tion.

According to my explanation, the momentary slackening of the current at its commencement is caused by a portion of its energy being taken up, and becoming static, in throwing the wire into a state of molecular tension; and the momentary increase of the force of the current at the moment when it is cut off is caused by the energy that was static in the wire returning to the state of kinetic, or current, electricity.

I have now stated the most important facts of electro-dynamic induction, and, as I believe, given a satisfactory interpretation of them. And I believe, though the evidence is not nearly so

Electro-
static
nduction,

strong, that electro-static induction, as in a Leyden jar, will be explained in some similar way; namely, that the electric charge consists in some kind of molecular tension.

The explanation I have given above applies only to those momentary currents which are produced by induction; it does not apply to continuous currents. But I believe that the hypo-thesis of molecular tension will be found to explain the facts of

and con-
tinuous
currents,
probably
both due
to mole-
cular
tension.

continuous currents also. The molecules of a conductor along which a current is flowing are, I think, shown to be in a state of molecular tension (of a different kind, however, from that of wire B) by the fact that *all the successive portions of the same current repel each other :* as is easily proved by suitable experi-mental arrangements.[1]

Electro-
magnetic
induction.

With respect to the theory of electro-magnetic induction, however, there is no difficulty whatever : it admits of an ex-planation exactly parallel to that which I have given of electro-dynamic induction. In other words, the induction of momentary magnetism in a soft iron bar is an exactly parallel fact to the induction of a momentary current in a conducting wire.

Experi-
ment V.

Let an electric current be flowing along a wire coiled into a hollow spiral, and let a soft iron bar be put into the spiral; the iron will be instantaneously magnetised, and the current will for

Experi-
ment VI.

the moment become *less* forcible. On removing the bar it at once loses its magnetism, while the current, for the moment, becomes *more* forcible.

Explana-
tion.

These facts admit of exactly the same interpretation as those of induced currents. When the iron is put into the spiral, and the current for a moment loses force, the slackening of the current is caused by a portion of its energy being taken up and becoming static in the iron, which it throws into a peculiar state

---

[1] De la Rive on Electricity, English translation, vol. i. p. 231.

of molecular tension, constituting the magnetised state. And
when the iron is taken out of the spiral, the energy that was
static in the iron becomes kinetic in the wire, and increases for
the moment the force of the current.

Thus the facts of electro-dynamic and of electro-magnetic
induction are not only themselves parallel, but admit of a
parallel interpretation ; and this tends to confirm it for both.

Besides this, there is other and more direct proof that soft
iron, when temporarily magnetised by the passage of an electric
current near it, is in a state of tension.

Instead of moving the iron bar into and out of the spiral
while the electric current is flowing, let the iron remain in the
spiral while the current is turned *on* and *off;* the act of turning Experi-
the current *on* will magnetise the iron, and the act of turning it ments VII.
off will demagnetise the iron.   and VIII.

It has been ascertained by Professor Joule, that at the moment Experi-
of turning the current on so as to magnetise the iron bar, the ment IX.
bar will be elongated by about a 720,000th of its length ; which Elonga-
increase of length it will lose in the moment of turning the iron bar
current off so as to demagnetise it.[1] This appears to be con- during
clusive evidence that the magnetised iron is in a state of magnetisa-
molecular tension.   tion.

This is still further confirmed by the very remarkable fact, Experi-
that when the iron bar and the wire spiral are placed as in the ment X.
last experiment, and the current alternately turned on and off
at the rate of several times in a second (which is easily done
by means of a mechanical arrangement), sounds are heard pro-
ceeding from the iron.[2] By turning the current alternately on
and off, the iron is alternately thrown into and out of a state of
tension.

If a *magnet* is put into a wire spiral like that used in the Sounds
former experiments, while there is *no current* flowing along the produced
wire, the approximation of the magnet will induce a momentary netisation.
current in the wire ; and if the magnet is taken out again,
another momentary current will be induced in the wire, but in
the opposite direction. It is on this principle, although the The
mechanical arrangements are different, that the magneto-electric magneto-
apparatus is constructed for supplying the electric light.   electric
                                                                  machine
Whence comes the energy of the induced currents in these

[1] De la Rive on Electricity, English translation, vol. i. p. 306.
[2] Ibid. p. 303.

experiments ?   It cannot be from the static energy of the
magnet, for the magnet loses none of its magnetism, and con-
sequently cannot have parted with any of the static energy to
which its magnetic state is due.   The magnets in Mr. Holmes's
electric lighthouse apparatus are stated by him rather to gain
than to lose force with use.   But if the kinetic energy of the
electric current had to be obtained by the transformation of the
static energy of the magnets, the whole stock would no doubt
be expended in a few seconds at the most.   The energy of the
transforms current is obtained by transforming the mechanical energy which
mecha-   is employed in moving the magnets.   The transformation takes
nical into
electric   place *under the influence* of the magnets, and would not take
energy.   place without them, but it does not take place *at their expense.*

CHAPTER IV.

PRIMARY FORCES.

WE have seen[1] that all energy has its origin in force: for instance, the force of gravity produces the energy *Force originates energy, but* of motion of a falling body. And as all forms of energy are capable of mutual transformation, it follows that any force may produce any form of energy. If gravity causes a body to fall, and in its descent it produces electricity or heat by friction, there is electricity or heat produced by gravity. But the converse is obviously not true; gravity may produce motion, but motion cannot produce gravity: *energy cannot originate* chemical affinity may produce electricity or heat, but *originate* neither electricity nor heat can produce chemical affinity. *primary forces.* The ultimate origin of all energy is in primary forces; and primary forces are defined as forces which do not originate *Primary forces de-* in any other forces, but are to be directly referred to the *fined.* laws of nature, and have their origin directly in creative power.

Thus the attractive and repulsive forces of a magnet or *Instances* of an electrised body are not primary forces, because they *of forces not pri-* are not to be referred to the ultimate properties of the *mary.* bodies. The electrical attractions and repulsions of a body that has been electrised by a common electrical machine are due to the charge of electric energy which the body has taken up; and this electric energy has been obtained by the transformation of the mechanical energy that worked the machine.[2] And the magnetic attractions and repulsions of an iron bar that is magnetised by the passage

<div style="text-align:center">

[1] P. 19.   [2] P. 30.

</div>

of an electric current are due to the charge of magnetic energy which, as I have endeavoured to prove, is obtained by the transformation of the energy of the electric current, and taken up and, as it were, for the time incorporated with the iron.[1] None of these forces are primary forces, because the bodies have acquired them and may lose them.

Three primary forces, gravity, capillarity, and affinity.

There are three, and only three, kinds of primary force. These are : 1, Gravity ; 2, Capillary attraction ; and, 3, the attraction of chemical elements that seek to combine (as, for instance, oxygen and hydrogen, or oxygen and carbon), or, to use the common but very infelicitous term, chemical affinity. For the sake of brevity let us call these gravity, capillarity, and affinity. Capillarity is of much less importance than the other two, but I mention it in order to make the enumeration complete.

Their properties.

Gravity acts at all distances, and is for that reason a force acting on masses—a *molar* force. Capillarity acts only at insensible distances ; in other words, it acts only when bodies are in immediate contact. It is for that reason a force acting on molecules—a *molecular* force. Affinity also acts only at insensible distances ; but there is this difference between capillarity and affinity, that capillarity acts on the molecules into which a body may be broken up by mere mechanical division, while affinity acts on the chemical atoms which are the constituent parts of the molecules. Affinity is consequently an *atomic* force.[2]

Gravity, acting at all distances, is, probably for that reason, always in action—all matter is always attracting all other matter. Capillarity and affinity, acting only at insensible distances, act, probably for that reason, only under favourable circumstances ; capillarity is chiefly

[1] See Note to Chapter III.
[2] When I speak of molecules and atoms, I only mean the smallest integrant and constituent parts, without implying any opinion as to whether or not these are infinitely small. I speak of the molecules of a body in the same way that mathematicians speak of infinitely, or indefinitely, small arcs of a curve.

confined to the liquid state of matter; and affinity gene-
rally, if not always, requires a certain degree of eleva-
tion of temperature before it will act. Combustion, for
instance, which is the most energetic of all chemical
actions, in most cases will only commence at a very high
temperature, and never, so far as I know, at a very
low one.

Gravity is incapable of saturation; that is to say, what-
ever be the quantity of matter that any mass of matter is
attracting, it is capable of attracting any additional quan-
tity with exactly the same force as if it had no other to
attract. In briefer language, all matter attracts all other
matter. Capillarity, on the contrary, is capable of satu-
ration: as capillarity acts between molecules only when
they are in contact, the capillarity of a molecule of (for
instance) water or mercury for other molecules of the same
liquid is in a state of saturation so long as it is surrounded
by other molecules of the same liquid; all its capillarity
is employed in attracting them, and it cannot attract, or
be attracted by, any more. Affinity also is capable of
saturation. One volume of hydrogen, for instance, does
not attract all oxygen, but only one half-volume of oxygen;
and when these are combined to form water, their affinity
for each other is saturated; the water has no further
affinity for either hydrogen or oxygen.

Gravity is not an elective force; that is to say, it acts on
all matter alike: all matter attracts all other matter with
a force directly as the mass. Capillarity, on the contrary,
is elective; that is to say, some, probably all, liquids have
a stronger capillarity for some substances than for others.
Mercury, for instance, has a strong capillarity for itself, as
is shown by the way it runs into globules; but it has very
little capillarity for other substances, except metals. Oil,
on the contrary, has a stronger capillarity for most solids
than for itself, as is shown by its rising in a wick and
spreading over surfaces, in opposition to gravity. But oil
and water, or water and mercury, have hardly any capil-
larity for one another, and refuse to mix, or even to adhere.
Affinity also is elective: oxygen, for instance, has a very

strong affinity for hydrogen, carbon, and iron, but hardly any for nitrogen.

The potential energy due to gravity becomes actual by the falling of bodies, in which act it is transformed into energy of motion. When the potential energy due to capillarity becomes actual, it also is transformed into energy of motion: this takes place when two drops of mercury or of water rush together. But affinity differs fundamentally from these two, in that its potential energy, when it becomes actual, is not transformed into energy of motion, but into heat or electricity. Combustion is not only the most familiar but the best instance of the transformation of chemical potential energy: the heat of combustion is the transformed energy due to the affinity of the oxygen and carbon that combine in the act of combustion. But in many cases of combination it is possible, by means of the arrangement of the voltaic battery, to obtain it in the form of electricity instead of heat.

When the potential energy of gravity or capillarity becomes actual, the change in the form of the energy does not determine any change in the character of the bodies. Water, for instance, does not change its character in falling, nor do drops of water change their character as water in rushing together by reason of their capillarity. But when the potential energy of affinity becomes actual, the transformation of the energy is always accompanied by a change in the character of the substances; they combine, and the compound has properties unlike those of either of the constituents.

Summary of their properties. To sum up: Gravity acts at all distances and at every moment; it is incapable of saturation, and is not elective. Capillarity and affinity, on the contrary, act only at insensible distances, and under favourable circumstances; they are capable of saturation, and are elective. Gravity and capillarity, when their potential energy becomes actual, produce it as motion, and the character of the substances remains unchanged. Affinity, on the contrary, produces the energy in the form of either heat or electricity, and

the substances combine, forming a compound with new properties.

It is a very important generalization, that *all primary forces are attractive;* there is no such thing in nature as a primary repulsive force. For this, as for every other ulti- mate physical law, no *cause* can be assigned except the Divine will. But its *purpose* is obvious. The universe is held together by attractive forces; and if, as I believe, the nebular, or, as I prefer to call it, the condensation theory of world-formation is true, the universe has been formed by the action of attractive forces. Repulsive forces, on the contrary, it is obvious, could neither form a world nor hold it together.

All primary forces are attractive.

Purpose of this.

It needs no proof that gravitation and capillarity are attractive forces. In the case of affinity this is not quite so evident. But we know that the action of chemical forces tends to union, and not to separation; and we know also that it tends to condensation. The proof of this latter assertion is, that (among gases, in which alone it is pos- sible to study chemical forces purely and simply) the volume of a compound is *often less* than the joint volume of its constituents when uncombined, and *never greater*.[1]

From the truth that all primary forces are attractive, it follows that potential energy is never *in a body*, but always *between two bodies;* being due to their mutual attraction, for attraction must be between at least two things. The energy due to the mutual attraction of two bodies is not a function of either body separately, but a joint function of the two. The potential energy due to a weight that is ready to fall is a function neither of the weight nor of the earth that attracts it separately, but of both jointly. The potential energy due to the capillarity of two rain-drops that are ready to run together is a function of neither

Potential energy is a joint func- tion of two mutually attracting bodies.

---

[1] The immediate effect of the combination of oxygen and hydrogen is an increase of their volume so great as to be capable of causing an explosion. But this is due to the production of heat ; and if the water, which is the result of their combination, is in the form of vapour, or steam, at the same temperature and pressure as the oxygen and hydrogen before combination, it occupies only two-thirds of their joint volume.

separately, but of both jointly. And the potential energy due to oxygen and carbon that are ready to burn together, is a function of neither separately, but of both jointly.

No distinction between combustibles and supporters of combustion. It follows from this last remark, that the common distinction between combustible substances and those which support combustion has no foundation in the nature of things. We can burn a jet of oxygen in an atmosphere of hydrogen, just as we can burn a jet of hydrogen in an atmosphere of oxygen. The definition of combustion is *the rapid combination of two substances* (of which oxygen is generally, but not always, one) *with great production of heat ;* and the one burns as truly as the other.

Forces belong to the original constitution of matter. Another result of the highest importance is, that matter is endowed with active forces, as a part of its original constitution.

The laws of the conservation of momentum, the conservation of rotation, and the conservation of energy, have nothing to do with the nature of the force, or with the source of the energy; they are equally true, whether the forces that we have to consider in any case are primary forces, like gravity, or acquired ones, like magnetism : and they are equally true, whether the energy is the result of the mutual actions of the bodies under consideration, as for instance in a steam-engine at work; or whether it is the result of some force that has acted from without, as **Theory of Descartes** when we spin a gyroscope. It was, I believe, the opinion of Descartes, and regarded as probable by Locke, that matter had no dynamical properties except the merely passive capacity of being acted on by force, and of transmitting the action on to other matter : that it was by its original constitution without active forces, and was set in motion by the same supernatural Power that created it. I do not see how this theory was ever reconcilable with the most obvious of all dynamical facts, that of weight; and all that modern research has taught of dynamics and **disproved.** chemistry proves the theory to be entirely wrong; it shows that matter possesses, as part of its original constitution, not only passive properties, but the active forces of gravity, capillarity, and affinity. In other words, matter possesses,

as part of its original constitution, not only the capacity
of being acted on by force, but the power to exert force on
other matter.

But the progress of science has not only made it certain Matter
that matter has active dynamical properties as well as may have
none but
passive ones; it has made it doubtful whether matter has dynamical
any other than dynamical properties. properties.

It used to be said that matter was extended and im-
penetrable. But what we have learned of general and
chemical dynamics makes it possible, and perhaps pro-
bable, that matter, in its ultimate constitution, is not
extended; for it is as likely a supposition as any other, May not be
that the ultimate molecules of matter are mere points, extended,
having position and mobility, but no magnitude or ex-
tension; which points, however, are the centres of various
kinds of attractive forces by which they act on other
molecules, and are also endowed with the passive capacity
of being acted on by similar forces proceeding from those
others. If this is true, it follows also that matter, in its
ultimate constitution, is not impenetrable. "The impene- and not
trability of matter" means that two portions of matter impene-
trable.
cannot occupy the same space. But the facts of chemical
combination appear to contradict this; for in many cases
the compound occupies less space than the sum of the
spaces occupied by its constituents before combination
(in the case of watery vapour, for instance, only two-
thirds); and the most obvious interpretation of such facts
is, that the ultimate atoms of the two constituents coalesce,
and occupy the same point in space. On this supposition,
the atom of water, for instance, consists of an atom of
hydrogen and one of oxygen, which have coalesced and
come to occupy the same point.[1]

I do not say that this theory of the nature of matter
is true: I say it is possible; and that we consequently

[1] On this subject of the constitution of matter, see Faraday's Essays on
Physics, in which he has revived Boscovich's theory of matter, according
to which matter consists of mere mathematical points, which are centres
of various kinds of force; and applied it to chemical facts that were
unknown to Boscovich.

cannot safely assert that any properties necessarily belong to matter (other than position in space and mobility) except active and passive dynamical ones; that is to say, except the power of acting by its forces on other matter, and of being acted on in return. We thus know matter only as a function of force, just as we know force only as a function of matter.

CHAPTER V.

CHEMICAL ENERGIES.

WE have seen[1] that the quantity of energy given out in
the fall of a weight is proportionate to the weight
multiplied into the height through which it falls; and
that this energy is exactly sufficient to raise it again to
the height from which it has fallen. This last is a result
of the law of the conservation of energy.

It is equally true that the quantity of energy that is Energy
given out, in the form of heat or electricity, by the com- given out
in combi-
bination of any two elements, is proportionate to the nation, a
constant
quantity of the compound formed, being constant for the quantity,
formation of equal quantities of the same compound.
One pound of hydrogen, for instance, in uniting with
oxygen to form water, gives out as much heat as would
raise the temperature of 34,462 pounds of water by one
degree centigrade.[2] And it is a result of the law of the and suffi-
cient to
conservation of energy, and is amply proved by experiment, decompose
that the energy given out in the formation of a given the com-
pound.
quantity of water or any other compound is exactly suffi-
cient, if it were applied in the form of a current of
electricity, to decompose the compound back into its
constituent elements.

Of course it is not possible actually to decompose a
pound of water by the energy given out in the formation
of another pound of water. In chemical experiments
there is always great loss of energy by what may be com-

[1] P. 19.
[2] All the numerical data referred to in this chapter are given in the
Appendix to Miller's Chemistry, on the authority of Fabre and Silbermann.

pared to friction : the energy so lost, as in mechanical friction, is converted into heat and dissipated, and cannot be got back.

Gravitation and affinity.   The spontaneous combination of elements, in consequence of their mutually attractive force, may be compared to the fall of a weight by gravitation; and the separation of elements by electro-chemical decomposition, in opposition to their mutual attraction, or affinity, may be compared to the forcible lifting up of a weight. When the weight falls, or when the elements combine, potential energy becomes actual; when the weight is lifted, or when the compound is decomposed, actual energy becomes potential.

Energy once become actual has been parted with.   It is most important clearly to understand, that in all cases of spontaneous combination the energy *has been parted with.* In ordinary dynamics every one understands this : every one is perfectly well aware that when the water of a mill-stream has fallen so low that it can fall no lower, it is impossible to get any more motive power out of it, **Misconceptions.** and motive power means *useful* energy. But in chemistry it is not universally understood. Intelligent men still speak of the power, or energy, *locked up* in every drop of water, when they ought to speak of the energy that *was given out* millions of years ago, when the water was formed by the combination of oxygen and hydrogen ; and to speak of it as energy, or motive power, is the same kind of error that it would be to speak of the pressure of the ocean on . its bed as if any motive power were due to it. Water is burnt hydrogen, and hydrogen, or any other com- **Anecdote of an iron-master.** bustible, will not burn again after being burned. A story is told, and is not at all too good to be true, of an iron-master who had learned enough of chemistry to know that water is composed of a combustible substance and a supporter of combustion : he inferred that it must have the properties of both its constituents, and tried the experiment of blowing a furnace with steam instead of air, but of course he only blew it out.

When two moving bodies come into collision and bring each other to rest, we say that their opposite momenta have

destroyed, or neutralized, or cancelled each other ; and this
statement is true, but it is not the whole account of what
takes place.   It does not tell what has become of the
energy due to the motions that have disappeared.   This
energy, however, has been transformed into heat.   Just in
the same way, when we say that water is formed by the com-
bination of oxygen and hydrogen, this statement is true,
but it is not the whole account of what takes place.   In
order to give a full account of it, we must say that water
is formed by the combination of oxygen and hydrogen,
and the liberation of a definite quantity of energy in the
form of heat.   Energy is as real as matter, and the libera-
tion of the energy is as essential a part of the process as
the combination of the oxygen and hydrogen.

Though the facts of chemical dynamics which I have
stated are universally recognised as true, I am not sure
that their importance is yet in general sufficiently felt,
even by scientific men.   I proceed to submit the plan
of an addition to the chemical notation in general use,
which would, I believe, give them no more than their
due prominence.

In the preceding part of this chapter, I have endeavoured
to make the subject intelligible to any person of ordinary
intelligence, who is willing to give it the needful attention.
In what follows, on the contrary, it is necessary for me
to presume on the reader's acquaintance with chemical
notation.

When two substances spontaneously unite and form a
compound, as for instance when a volume of hydrogen
unites with half a volume of oxygen to form a volume of
watery vapour, we write the symbol of the compound in Chemical
such a form as this : (I use the new notation, in which the notation
expressive
equivalents of all substances, when in the gaseous or of combi-
vapoury state, are supposed to have equal volumes :)—   nations.

$$H\ O^{\frac{1}{2}}\ ;$$

and this is a true statement, but it does not state the
whole of what takes place ; for it tells nothing about the
energy which, in the act of combination, is transformed

from the potential into the actual state, and given out as
heat or electricity. Yet energy has as real an existence,
and is as definitely measurable by quantity, as oxygen or
hydrogen; and consequently, in order to give a full
account of what takes place so far as a formula can give
it, the equation ought to state not only what elements
combine, and in what proportions, but also how much
energy is given out in the act of their combining.

I propose to do this as follows. The quantity of heat
that will raise the temperature of a pound (or any other
unit-weight) of water by 1° centigrade is called by writers
on the subject a *heat-unit*. As already stated, the com-
bination of a pound of hydrogen with oxygen, so as to
form water, gives out enough of heat to raise the tem-
perature of 34,462 pounds of water by 1° centigrade. In
other words, 34,462 heat-units are given out in the forma-
tion of water, and 34,462 is the *thermal equivalent* of
water. I propose to write θ as the symbol of a heat-unit.
The symbolical expression for water will then be :—

$$H\,O^{\mathrm{i}} - 34{,}462\ \theta;$$

indicating by the use of the negative sign that the heat,
or its equivalent in electricity, *has been parted with:* and
when the sign of the thermal equivalent is negative, I
propose to call the compound *thermo-negative*. All com-
pounds formed by the spontaneous combustion of their
elements are thermo-negative : that is to say, heat has
been given out in their formation. Products of perfect
combustion, such as water and carbonic acid, are neces-
sarily thermo-negative.

But with some substances the sign of the thermal
equivalent is positive : and I propose to call them *thermo-
positive* substances. Nitrous oxide is one of these. Its
symbol, written as I propose, is[1]

$$N\,O + 9{,}232\ \theta;$$

Proposed addition to it.

Heat-units.

Thermal equiva-lents.

Thermo-negative and

thermo-positive compounds.
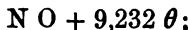
[1] "In the experiments of Dulong it appeared that when oxide of carbon,
or hydrogen, was burned in protoxide of nitrogen [nitrous oxide], a larger
amount of heat was evolved than when the same weights of these gases
were burned in oxygen. Following up this observation, Fabre and Sil-
bermann were led to the remarkable conclusion that protoxide of nitrogen,

that is to say, instead of giving out heat in the act of formation, it takes up 9,232 heat-units, which reappear as heat when it is decomposed.

Thermo-positive compounds are never products of combustion, but are always formed by indirect methods. As a general rule, they appear to be less stable and more chemically active than thermo-negative compounds. Many compounds of nitrogen are chemically very active ; nitrous oxide, already mentioned, is by no means the most remarkable of these. Gun-cotton and the fulminating salts are compounds of nitrogen, and are in all probability highly thermo-positive. It has often excited surprise that the compounds of nitrogen should be so active when nitrogen is itself so inert, but most probably the inertness of uncombined nitrogen is in some way connected with the power of nitrogen to take up large charges of energy in its compounds.

Peroxide of hydrogen is from this point of view a very remarkable substance. It is altogether misleading to write its symbol Peroxide of hydro. gen,

$$H\ O.$$

It is really a thermo-positive and very unstable oxide of water:[1] it is easily decomposed into water and oxygen, and in this decomposition heat is produced. Writing water as before,

$$H\ O^{\frac{1}{2}} - 34{,}462\ \theta,$$
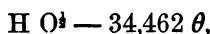
peroxide of hydrogen should be written

$$(H\ O^{\frac{1}{2}} - 34{,}462\ \theta)\ O^{\frac{1}{2}} + 10{,}904\ \theta.[2]$$
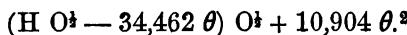
in the act of decomposition, evolves a considerable amount of heat: and they estimate that not less than 1,154 units of heat are evolved in the separation into its elements of a quantity of nitrous oxide which contains one gramme of oxygen." (Miller's Chemistry, Appendix.) Multiplying 1,154 by 8 for the atomic weight of oxygen, we have 9,232, the thermal equivalent in the text.

[1] It is not necessary for my present purpose to enter on the question as to its being a compound of antozone with water.

[2] Fabre and Silbermann "estimate the heat evolved during the liberation of one gramme of oxygen from peroxide of hydrogen at 1,363 heat-units." (Miller's Chemistry, Appendix.) Multiplying by 8 as before, we have 10,904 as the thermal equivalent.

I do not propose this notation as adapted for general use, but I believe that it would be a concise and lucid way of stating important facts: and it could not cause any confusion, because the present notation would not be in any degree changed, but only added to.[1]

But what is there in a thermo-positive compound to represent the energy that appears as heat on its decomposition? I cannot suggest any answer whatever to this question. It is a form of static actual energy, but, unlike electricity and magnetism, it does not appear to be any kind of strained elasticity.

Nor can we tell what there is, in or between[2] two elements previous to their combination, to represent the energy that they give out, as heat or electricity, on their combination. The emission of heat is not due, as Lavoisier supposed, to condensation. Such a cause is probably inadequate in nearly all cases, and in the case of the combination of hydrogen with chlorine it fails altogether; for after they have combined and formed hydrochloric acid gas, they continue to occupy the same space as before. The tendencies of elements to combine, and to give out energy on combining, are in all probability ultimate properties, no more to be explained or accounted for than gravitation. But this very important question remains for solution: Can we assign dynamic equivalents to the elements? We know the thermal equivalents of many products of spontaneous combination, as water, hydrochloric acid, and carbonic acid. Can we assign dynamic equivalents to their elements, so that the thermal equivalent of any compound (that is to say, the quantity of energy which from being potential in the elements becomes actual in the act of combination) shall be the sum, or the product, or some other joint function, of those equivalents of their elements?—just as the potential energy due to

Dynamic equivalents of the elements.

---

[1] It might also prevent mistakes from being made by classing substances of unlike thermo-chemical properties in the same or homologous series. But I do not know enough of the higher chemistry to be certain whether there is any danger of this.

[2] See p. 43.

the mutual gravitation of two bodies is proportionate, supposing the distance given, to the product of their masses.

What greatly increases the difficulty of any such inquiry is, that in the case of many thermo-negative substances, the potential energy of their elements is not all parted with in the act of combination; some of it remains in the compounds, and is converted into heat when they again enter into combination. To take an instance almost at random, hydrochloric acid and potash are both thermo-negative; and yet when an equivalent of the one combines with an equivalent of the other, they give out no less than 15,656 heat-units. Neutral salts are perhaps the only perfectly thermo-negative substances : and, containing no potential energy, they do not seek to combine with others. They may be compared to a body which has no potential energy due to its position, and is in stable equilibrium because it can fall no lower.

In order to discover these dynamic equivalents (if they exist, which appears highly probable), it will of course be necessary in the case of each element to observe the quantities of heat it gives out in combining with various other elements, and the quantities its compounds again give out in their combinations. The problem is no doubt a difficult one, but it ought not to be very much more difficult to us than was the determination of the combining equivalents to Dalton.

Some simple substances appear to be capable of entering into a thermo-positive state. Phosphorus is the most remarkable instance of this yet known : it is capable of assuming the allotropic state called red or amorphous phosphorus, in which it has taken up a considerable quantity of heat. If red phosphorus is heated up to a certain point, it suddenly passes back into the ordinary colourless state, and the heat which it had taken up is given out in such quantity as to vaporize a part of the phosphorus.[1] The number of heat-units has not been determined, so far

Red or amorphous phosphorus.

[1] Miller's Chemistry, vol. ii. p. 201.

as I am aware.   If we call it x, then, the symbol of common phosphorus being

$$P,$$

that of red phosphorus, in the notation that I propose, will be

$$P + x\,\theta.$$

NOTE.

Inaccurate language respecting affinity as a force.

VAGUE and inaccurate language is still general concerning the relation of chemical affinity to the various forms of energy. Thus Mr. Grove says :—

"Light, heat, electricity, magnetism, motion, and chemical affinity are all convertible material affections."[1]   And again, "Lastly, electricity produces *chemical affinity*."

Now, it is quite true to say that light, heat, electricity, magnetism, and motion are all convertible, being all forms of energy, and capable of mutual transformation.   But chemical affinities are not capable of transformation into anything else; so far as our knowledge extends, they appear to be primary forces ;—primary underived properties of matter, and unchangeable by any action whatever.   Oxygen and hydrogen, for instance, have an affinity for each other which nothing can change, or transform into anything else.   While they are uncombined, this force of affinity *makes them seek to combine ;* after they are combined, it *resists decomposition*.

I do not suspect Mr. Grove of any inaccuracy as to fact, or any confusion of scientific thought.   I believe the expressions I object to are mere inaccuracies of language, occasioned by the proper technical language of the subject being not yet fixed. When Mr. Grove says that electricity produces chemical affinity, I presume he means that, in the electric decomposition of water or any similar substance, the electric energy is transformed into the chemical potential energy due to the mutual affinity of the separated elements.

As gravity produces motion, but motion cannot produce gravity, so affinity produces heat or electricity, but heat or electricity cannot produce affinity.

[1] Correlation of Physical Forces, ed. 1862, p. xii.

CHAPTER VI.

THE MOTIVE POWERS OF THE UNIVERSE.

WE have seen that matter and energy are incapable of being either produced or destroyed, and capable only of being transformed; and it is an obvious inference from this that the universe has existed from an eternal past, and will continue to exist through an eternal future. It appears at first sight a probable theory that all changes that go on in the universe are like the motions of the planets in their orbits, which, after a shorter or longer period, end at the point where they began. It appears as if we had good ground for the belief, which was that of many ancient philosophers, that cosmic changes (to use a mathematical metaphor) move in closed curves ; and that at the end of a finite though very long cycle, or *annus maximus*, all things will return to their state at its beginning.

But a profounder knowledge of the laws of energy shows that such an inference is untrue. It shows that the universe has not existed from an eternal past. It shows that cosmic changes do not come back to the point where they began : that they do not move in closed curves, but in open spirals; though in the historical periods these spirals are not distinguishable from closed curves.

The reason of this is the destruction of motive power which is always going on. Energy is indestructible, but motive power is constantly diminishing in quantity. Motive power is defined, for the purposes of the mechanic, as *useful energy* — energy that he can transform as he

desires. In a broader scientific sense, motive power is to be defined as *energy that is capable of transformation* into some different form of energy;[1] and in this sense, energy is not always motive power. Potential energy, as we have seen, is capable of transformation into actual, and the actual energies of motion and electricity are capable of transformation into heat. But the converse is not necessarily true. All other forms of energy are capable of transformation into heat, but heat is not always capable of transformation back again into other forms of energy. The heat in the furnace of a steam-engine is capable of being used as motive power; not because the furnace is *hot*, but because it is *hotter* than the surrounding air. But if the surrounding air were as hot as the furnace, and no supply of cold air or cold water could be brought in, no part of the heat could be converted into motive power. *Heat is capable of becoming motive power only in the act of attaining to equilibrium:* and consequently, *no motive power is due to heat in perfect equilibrium.*

Heat is not always motive power.

Illustration from a steam-engine.

Suppose the case of two bodies of unequal temperatures, which for the sake of a practical illustration let us call the boiler and the condenser of a steam-engine; and suppose that the heat of the boiler is flowing towards the condenser, so as to establish equilibrium. If the condenser is perfectly cold, all the heat of the boiler is theoretically capable of being used as motive power; but if the condenser, though colder than the boiler, is not perfectly cold, only a portion of the heat of the boiler can be so used. This last condition is the one that always occurs. Perfect cold is never found, nor can it be obtained by any known process: perfect cold—the absolute zero of temperature, or the total absence of heat—would be 492° Fahrenheit below the temperature of freezing water. Consequently, under the most favourable circumstances

---

[1] To be rigidly accurate, we should say that motive power is energy that is capable of transformation into some different form of energy, *other than radiance.* Heat is motive power in being transformed into motion, but it would be absurd to say that heat is motive power in being transformed into radiance—that is to say, in being radiated away.

that can occur, in any natural or artificial combination, only a portion of any mass of heat can become motive power.

The whole of what I may call a *mass* of energy of motion is capable of being transformed into heat. For instance, when a railway train is stopped by the action of its break, the energy of its motion is all transformed into heat. This transformation is constantly and everywhere going on throughout the world; it almost always takes place when motion ceases. But, as we have seen in speaking of the steam-engine, the whole of what I may in like manner call a *mass* of heat is *not* capable of being transformed into energy of motion,[1] or into any form of potential energy.

Thus any mass of energy of motion *can* be *all* transformed into heat, but the heat *cannot* be *all* transformed back into energy of motion. It follows from this, that though both of these transformations are constantly going on, more energy of motion is transformed into heat than can be transformed back again; and, as these are by far the most abundant forms of actual energy, the energy of motion in the universe is being gradually transformed into heat. Of course we do not assert that all the energy of motion in the universe will ever be thus transformed. We do not assert it of the planetary motions. But it is certain that such is the tendency of all change. *Transformation of energy of motion into heat, the prevailing tendency.*

We thus see that motive power is constantly transforming itself into heat, and that heat is constantly attaining equilibrium: and heat in equilibrium, as we have seen, is not motive power. It follows from this that a constant destruction of motive power is going on throughout the universe; there is less motive power in existence at present than there was in the past, and there will *Consequent destruction of motive power.*

[1] The relation between heat and electricity is in this respect the same as that between heat and energy of motion. Heat can be transformed into electricity only in the act of attaining equilibrium: when heat is in equilibrium, it cannot be transformed into electricity, or into any other form of energy whatever. The whole of a mass of electricity can be transformed into heat, but the whole of a mass of heat cannot be transformed into electricity.

be less motive power in the future than there is in the present.

Dissipa-
tion of
energy.

This is called the law of the *dissipation of energy.* For my present purpose I prefer to call it the law of the *destruction of motive power.*

It follows from this law, that, as I have stated at the commencement of this chapter, the changes of the universe do not come back to the point from which they began: the diminishing quantity of motive power makes a difference.

Consequences of the greatest importance to science follow from the two closely united truths, that energy is invariable in quantity, and that motive power is constantly diminishing.

Earth's
internal
heat is
constantly
being lost.

Among other inferences may be mentioned that as the earth is constantly though slowly parting with internal heat by volcanic eruptions, by hot springs, and by slow conduction outward through the strata; and as all volcanic action depends on heat—not eruptive action only, but all subterranean action whatever; it follows, as I believe, that the intensity of volcanic action has been constantly diminishing ever since the formation of the earth; and

Geological
conse-
quence.

consequently, that geological changes went on in past times with greater rapidity than they do at present.[1] I admit that geological evidence of this is scarcely to be hoped for, but I regard it as an *à priori* certainty.

Sun's heat.

What is true of the heat of the earth is also true of the heat of the sun. The sun is radiating away his heat, and it must be exhausted if fresh supplies are not brought in from without. But our increasing knowledge of the physics of the universe has suggested a mode in which such supplies may probably be brought in.[2] It has been proved beyond

Meteoric
theory.

all reasonable doubt, that the meteors which flash across our sky are small planets that fall from without into our

[1] I do not believe there is any evidence in favour of the chemical theory of volcanic action. But should that theory prove true, the conclusion in the text will not be affected; for energy from a chemical source obeys exactly the same laws as energy from a mechanical source.

[2] See Professor (now Sir William) Thomson's article on the subject in the Philosophical Transactions for 1854.

atmosphere; and the energy of motion that they had as
planets is transformed into heat by friction against the air.[1]
Their brilliant light is due to intense heat, and when they
fall as meteoric stones, these stones are intensely hot.
This is at least a possible origin of solar heat.   It is
calculated that a meteor, falling into the sun's atmosphere
with the velocity of a planet at the surface of his atmo-
sphere (and it cannot fall in with a less velocity than this),
has energy of motion enough to be converted into a rather
greater quantity of heat than would be produced by the
combustion of four thousand times its weight of coal.[2]

This hypothesis has received a very strong confirmation Carring-
by Mr. Carrington and another observer simultaneously, at ton's obser-
vation.
different places, on the 1st September, 1859, seeing two
meteor-like bodies of such brightness as appeared bright
against the sun, suddenly appear, rapidly move across his
disc *from west to east*, and soon disappear.

There are some further reasons in favour of the meteoric
theory which are little known, and are worth stating here.[3]

If there are small planets revolving round the sun and
constantly falling into his atmosphere as meteors, they
probably occupy, like the entire solar system, a lenticular
(or very oblate spheroidal) space, having its greatest
diameter nearly coincident with the sun's equator; and
if so, a greater number of meteors must fall on the equa-
torial than on the polar regions of the sun, making the
former the hottest.   Such is the case.   Secchi of Rome, Sun
without any theory to support, has found by the use of a hottest
at the
thermo-electric test (the result of which is due not to the equator,
ratio but to the *difference* of the two sources of heat) that and why.
the sun's equator is sensibly hotter than his poles.[4]

[1] And also, as has been suggested, by the compression of the air before
them as they fall.   It is to be remembered, however, that equal quantities
of energy of motion are convertible into equal quantities of heat, in what-
ever way the transformation is effected.

[2] Tyndall on Heat as a Mode of Motion.

[3] What follows, on the motions of the solar spots, and on the difference
of temperature at the sun's poles and equator, was first published by me in
a paper read at the Newcastle meeting of the British Association in 1863,
and printed in its Transactions.

[4] Nichol's Cyclopædia of Mathematical and Physical Science.

If these small planets move round the sun, it cannot be doubted that, like the larger planets, they move from west to east. Mr. Carrington's meteor, as already mentioned, moved in that direction. If, now, meteors are constantly falling into the sun's atmosphere, moving from west to east with the velocity of a planet at the sun's surface, and in greatest number nearest the equator, there is a motive power which may be expected to drive the atmosphere round the sun in the same direction, and with greatest velocity at the equator. Mr. Carrington's observations on the motion of the solar spots appear to show that such is the case. The solid globe of the sun is concealed by clouds, but Mr. Carrington has ascertained that the spots which are formed among the clouds of his atmosphere move most rapidly from west to east in the lowest latitudes, showing the relative dírections of the atmospheric currents to be what the meteoric theory requires. If on the contrary the sun's atmosphere, like the earth's, were acted on by no other motive power than unequal heating at different latitudes, the relative direction of the currents would be the reverse of this, in virtue of the well-known principle of the trade-winds and " counter-trades," and this would be true at all depths in his atmosphere.

The meteoric theory does not, so far as I can see, throw any light on the difficult question of the nature of the solar spots, but it suggests a reason why they should be formed where they are. They are formed only in the lower latitudes of the sun, where, as already remarked, the greatest number of meteors probably fall in, and where consequently there must be the most atmospheric disturbance.

If the sun is still receiving supplies of energy for conversion into heat, and is not merely expending an original stock, the falling in of meteors is the only possible mode of such supply. The most obvious notion is that solar heat is heat of combustion. But combustion is altogether an inadequate source. We have seen that the energy of motion with which a meteor will fall to the surface of the sun is equivalent to a greater quantity of heat than that which would be produced by the combustion of four

thousand times its weight of coal; and if the quantity of
heat constantly radiated by the sun were supplied by the
combustion of the sun's substance, supposing the sun to be
of coal, and oxygen to be supplied from without, it would
be burned away in about 26,000 years [1] at the most.

I ought perhaps to repeat, that meteoric heat is the Meteoric
energy of motion of the meteors, which is transformed into heat.
heat in the act of falling into the atmosphere of a sun or a
planet. The intensely bright light of the meteors that
flash across our sky shows how hot they must be; and
in consequence of the sun's greater attractive force, the
meteors fall into his atmosphere with a very much higher
velocity than into ours, and, of course, produce heat in the
ratio of the square of the velocity.

But, however strong may be the proof of the meteoric Infinite
theory of solar heat, it does not prove the supply of solar supply of
heat to be inexhaustible; for an endless supply of heat meteors
would need an infinite supply of meteors to yield it, and
an infinite supply of meteors could only be drawn from
infinite space. Such a supply may possibly be brought in ; possible,
there is nothing in the supposition in contradiction with but
the laws of force; but if, in the course of ages to which
all historical time is but a point, vast masses of meteoric
matter fall in from regions beyond the orbits of the planets,
and increase the sun's mass and consequently his attractive
power, this increase of the sun's attractive power, not would
being balanced by any increase in the centrifugal force subvert
of the motions of the planets, will ultimately cause the librium of
planets themselves to fall into the sun.   the solar
                                                             system.

Consequently, one of two alternatives must be true. If Two alter-
the supply of meteors is limited, the sun's heat will be natives :
                                                             exhaustion

---

[1] Were the heat radiated away by the sun supplied by the combustion
of coal, it would require the combustion every year of a layer of coal about
seventeen miles thick all over the sun's surface. (Tyndall on Heat, p. 419.)
As the sun's radius is about 441,000 miles, this would involve the com-
bustion of his whole substance in about 26,000 years. On this supposition,
however, the sun's mass, and consequently his surface, would be constantly
growing less, and would radiate less and less heat; but were the supply
by any means to be kept up at the present rate, the sun would be burned
out in a much shorter time.

of sun's heat, or subversion of equilibrium of the solar system. exhausted like that of a fire that dies out for want of fuel; and this, from what evidence we have, appears the most probable alternative. Or if the supply of meteors is indefinitely great, the increase of the sun's mass by their falling in will subvert the equilibrium of the solar system. And in neither case will the future be like the past and the present.

We have seen that the law of the conservation of energy proves that the sun is radiating away his stock of heat, and cannot possibly receive any considerable fresh supply except from without. And we have seen that the law of the dissipation of energy proves that the heat thus radiated away tends to equilibrium—to equality of temperature among all the bodies in the universe; and this involves destruction of motive power.[1]

Is the universe mortal? Are we then to infer that all things are tending to equilibrium, repose, and death?

Uncertain. On this subject we can only make conditional assertions, as we do not and cannot know all the data.

Three cases are possible.

First case. The universe may be finite in the midst of infinite space. In this case all the heat will be radiated away.

Second case. The universe may be finite in finite space. Space is no doubt geometrically infinite; but the space in which our universe exists may, for anything we know to the contrary, be bounded by space which is not pervious to radiance. In this case the heat will ultimately attain to equilibrium, and cease to be motive power.

In either of these two cases all things are tending to equilibrium of temperature, destruction of motive power, Third case. repose, and death. But a third case is possible, and has been hinted at in speaking of the possibility of an infinite supply of meteors being brought in from infinite space. The universe may be infinite, and in infinite space; the supply of motive power may be infinite, and may last Each separate system is mortal. through endless time. In that case, however, though the whole universe is immortal, every separate system of which it is composed must perish, as already explained, through

[1] See p. 56.

the subversion of its equilibrium; but other systems may
arise out of its ruins, or be warmed with the heat generated
by its destruction. It is physically quite possible that
meteors may continue to fall, through endless time, from
the regions of infinite space into the sun and the other
stars; that their mass and attractive power, being aug-
mented by the meteoric matter, may cause their planets to
fall on to their surfaces as gigantic meteors, still further
increasing their mass, and renewing their stock of heat;
. that the stars may in like manner rush together; and so
on, absolutely without end. Some one of these three cases,
under some modification, must be the fact; but it is, and
ever must remain, utterly useless to try to guess which is
the most probable.

But though the universe may be destined for a future A past
without end, it cannot have existed through a past with-
out beginning. The sun may go on accumulating meteoric
matter without end; but, as his magnitude is finite, he
cannot have done so without beginning. Aggregation of
masses is always going on; at the beginning, so far as we
can judge, there was no aggregation, but all matter existed
in a diffused state, as it appears to exist in the nebulæ
now. Physical reasonings will bring us no farther back
than this: " the things which are seen were not made of
things which do appear."

It will be seen that I believe in the nebular theory, Nebular
or, as it might be called, the condensation theory of the theory.
origin of the stars and planets. I regard that theory as
no mere hypothesis. It postulates nothing as a law of
nature which is not independently known to be true; and
its assumption, that the laws of nature have continued
unchanged since the beginning of things, is one that is
implied in all the reasonings of geology. We know that
the tendency of things is for masses to become more and
more aggregated together, and to give out heat in the pro-
cess: the laws of gravitation and of heat make this neces-
sary, and every meteor that falls on the surface of the sun
or of a planet is an instance of it. The nebular theory is,
simply, that this process has gone on from the beginning;

and that every aggregate—that is to say, every star and planet—has been produced by the aggregation, or condensation, of matter that was previously in a diffused form, perhaps somewhat like that of water in a cloud.

It is to be observed that aggregation may be repeated an indefinite number of times. The original nebula may have condensed into masses no larger than meteors, and these may have coalesced into planets; the planets may ultimately swell the mass of the sun; suns may rush together; and so on, absolutely without limit, if the universe is infinite.

The smallest excess of density in one part of a nebula above the rest will produce at that place a centre of aggregation; and round it the nebulous matter will condense into a star or a planet, much in the same way that a cloud condenses into raindrops.

Transfor-
mation of
energy in
the process
of conden-
sation.
All the energy in the nebula was at first potential energy. When motion began in consequence of the mutual gravitation of its parts, part of this was changed into energy of motion; and when any of the moving parts struck against each other and coalesced into masses, depriving each other of part of their momentum, a part of their energy of motion was transformed into heat. Such was the origin of the internal heat of the earth (and in all probability of all planets, except those which are so small as to rank as mere meteors);[1] and such is the process by which, according to the metoric theory, solar heat is still originated.

Solar and
volcanic
heat have
the same
origin.
We thus come to the wonderful but highly probable conclusion, that solar heat and volcanic heat are of the same origin.[2]

Potential
energy of
the origi-
nal nebula.
It has been calculated by Professor Helmholtz, that all the potential energy due to the mutual gravitation of the

[1] It is well known that the moon's surface contains marks of past volcanic activity, and this appears to be not yet extinct. (Quarterly Journal of Science for July 1867, p. 383.)

[2] The chemical theory of volcanic action is in my opinion completely disproved by the comparative absence of hydrogen flames in volcanic eruptions; for that theory requires the action of water as an oxidising agent, and this involves the liberation of hydrogen.

parts of the original nebulous mass that has condensed
into the solar system, has been thus transformed into heat
and radiated away, except $\frac{1}{454}$th part, which still remains.[1]
Part of this is the potential energy due to the distances
of the planets from the sun, and would be transformed
first into energy of motion and then into heat if the planets
were to fall into the sun; part is the energy of the planetary
motions.   In this calculation the heat of the sun and of
the heated centres of the planets is left out of the account,
as being almost infinitely small in comparison with the
energy just mentioned as due to the planetary distances
and the planetary motions.[2]

In a few words, the history of the transformations of
energy in the condensation of a nebula is this : First it is
potential energy due to the gravitation of the parts of the
nebula towards each other; this is transformed, first into
energy of motion, and then into heat; and finally the heat
is transformed into radiance, and lost in space.

We have seen that the condensation of a nebula must
necessarily result in the aggregation of masses with pro-
duction of heat.   It follows from the law of the conserva-
tion of rotation,[3] that, supposing the original nebula to have Rotation of
a slight initial velocity of rotation, the masses will rotate a nebulous mass.
on their axes and revolve round their common centre of
gravity, as we find those which constitute the solar system
to do.   But it also follows from the conservation of rota-
tion, that if the nebula has no initial rotation, no mutual
actions of its parts can cause the nebula, or the sum-total

[1] In this calculation it is assumed that the volume occupied by the
nebula was infinite.   This of course cannot be true, but it probably gives
a nearly true result.

The total mass, or weight, of the bodies composing the solar system
being approximately known, it is a matter of calculation to determine how
much energy, from being potential, would become actual, in the con-
densation of that mass of matter from a state of infinitely wide diffusion
into a globe having the density of the sun.

[2] The nebular theory was first advanced by Laplace ; the best account
of it that I know of is to be found in Herbert Spencer's Essays, where a
wonderful amount of cumulative proof has been assembled.   Of course I do
not offer my slight sketch of the theory as anything like complete proof,

[3] P. 17.

F

of the bodies formed out of it, to rotate. But the nebulous mass out of which the solar system has condensed was in all probability only an infinitesimally small part of the original nebula, which, though perhaps not actually infinite, was probably the origin of the whole starry system known to us. The first condensation of a nebulous mass produces, not globular, but very irregular forms: we see these in those parts of the original nebula that still remain as nebulæ : the motions due to the mutual attractions of irregular forms will be very complex, and will be further complicated by the resistance of the rarer medium to the motion of the denser aggregations. Our mathematics are utterly inadequate to predict what such motions would be, but we may safely assert that most of them, if not all, will be partly rotatory; and the law of the conservation of rotation will be satisfied by the rotations in opposite directions compensating each other, so that their algebraic sum will be nothing.

Solar radi-ance the great mo-tive power.   With the small exceptions of volcanic action and of the tides, all the motions on the surface of the earth have their motive power in solar radiance. It is this which sets the winds, the rain, the rivers, and the ocean currents in motion ; and it is the motive power also of animal and vegetable life; for the heat and motor energy of all living beings is due to the combustion of carbon and hydrogen, and the potential energy which becomes actual in that combustion is the transformed energy of the solar radiance that has fallen on living vegetables. The same is true of the heat given out by the combustion of coal: it is the transformed radiance of the sun, which, millions of years ago, fell on the pines and ferns of the coal formations, decomposed the carbonic acid of the air, and in doing so was transformed into the potential energy due to the separation of the carbon from the oxygen ; which energy reappears as heat in every coal fire.[1]

The tides.   This, of course, is not true of tidal action. The motive power of the tides is not solar heat, nor any heat

[1] Tyndall on Heat as a Mode of Motion, p. 430. This subject is to be further explained in the chapter on Vital Energy.

whatever; it is that other portion of the unexhausted energy of the original nebula which exists as planetary motion. So that whatever work is done by the tide (as for instance if it works a water-mill),[1] the energy transformed in doing that work is a part of the energy of motion due to the earth's rotation; and, by the friction of the tidal wave against the earth, the velocity of the earth's rotation is being constantly lessened, though by an immeasurably small quantity.

We thus come to the wonderful but highly probable conclusion, that the motive power of a tidal current and that of a wind-driven current have both of them the same origin, in the potential energy due to the gravitation of the parts of the original nebula on each other. Part of this potential energy was transformed into the energy of motion due to the earth's rotation, and in that form became the motive power of the tidal current. Another part was transformed into the energy of motion of meteoric masses, and this into solar heat; which, after it reached the earth, was transformed back again into the motion of the winds and currents.

Energy of wind and tide; their common source.

[1] Tyndall on Heat as a Mode of Motion, p. 425.

CHAPTER VII.

CRYSTALLIZATION.

M Y purpose in this chapter is not to write an elementary treatise on Crystallography, but merely to give such an account of the principal facts of that science as may

Contrasts and resemblances between crystals and organisms. enable me to show the remarkable contrast, and the yet more remarkable points of resemblance, between crystals and organisms. I will avoid technical language as much as possible, but I fear I shall not be able to make myself intelligible, except to readers who are acquainted with the fundamental conceptions of solid geometry.

The first and most obvious point of resemblance between crystals and organisms is, that every specimen of either a

Species and classes. crystal or an organism belongs to a species, having its specific characters; and the species of both group themselves into genera, and the genera into classes.

Crystalline species defined. A crystalline species is defined as *a body of definite chemical constitution, from which,* in virtue of unknown formative principles, *results a form having definite geometrical properties.* I say a form having definite geometrical properties, rather than a definite form; because the same crystalline species often contains specimens having very different forms, the " crystallographic elements " of which, however, are the same, as is hereafter to be explained.

There are, however, qualifications to be made in asserting the invariability of either the chemical constitution, or the crystallographic elements, among all the specimens of a

Foreign substances modify forms. crystalline species. The presence of foreign substances, or of (what is practically a foreign substance) an excess of one of the elements of a compound, often causes a sensible

degree of irregularity in the crystalline form. And if sub-
stances that crystallize in nearly but not quite similar Forms in-
forms are mixed together in solution, they will form mixed termediate
between
crystals, of a form intermediate between those proper to species.
the two substances.

The mention of mixed crystals brings us to a very
important analogy between crystals and organisms. Sub-
stances that crystallize in crystals of the same form are
called isomorphous substances : substances that crystallize
in crystals of nearly the same form are called plesiomor-
phous.[1] Isomorphous and plesiomorphous substances, as
just stated, crystallize together, forming mixed crystals;
but when the same water contains substances in solution
that crystallize in unlike forms, they do not crystallize
together, but form separate crystals. The fact that mixed
crystals can be formed when the crystalline forms are
similar, but not when they are unlike, is a parallel to the
facts, that trees may be grafted the one on the other, and Analogies
that organisms can breed together, when they are of the with
organisms.
same or of nearly allied species, but not when the species
are unlike. To state these facts in terms that will apply to
both crystals and organisms : if the unformed but forma-
tive material of two similar species is mixed together, it
will produce an intermediate form ; but this is not the case
when the species are unlike. This statement postulates as
true the now universally received theory of generation, of
which I shall have to speak farther on.

Also, as crystals of unlike species in a mixed solution
attract to themselves each its own material, so different
species of plants in the same soil draw each from the soil
the nutriment it needs; and the various tissues in an
organism separate each its own material from the sap or
blood.

Some substances have the property of crystallizing in Dimor-
phism.

---

[1] Isomorphism and plesiomorphism depend on similarity of chemical con-
stitution ; and isomorphous or plesiomorphous crystals contain equal
proportions of water of crystallization. Salts are similar in constitution
when they contain the same number of equivalents of different bases, but
not when they contain different numbers of equivalents of the same base.

two fundamentally distinct forms; that is to say, forms of which the "crystallographic elements" are different, and between which, consequently, no gradation is possible. Such substances are said to be dimorphous. Carbonate of lime is one of these: it forms crystals of the rhombohedral system which are known as calcspar, and crystals of the right prismatic system which are known as aragonite. Such crystals are to be regarded as distinct species.

As I shall have to show farther on, there are great differences of form within the limits of the same species; but these are not fundamental, and gradation between them is possible.

Crystals are bounded by plane surfaces: A crystal, when normally formed, is always bounded by plane surfaces which meet each other at angles. In organisms, on the contrary, there is no such thing as two plane surfaces meeting at an angle.

may be described mathematically. Spiral shells. In every crystal, all the faces stand in simple mathematical relations to each other. In organisms, on the contrary, the forms are too complex to admit of mathematical description. Spiral shells are an exception to this: they present regular equiangular spirals. But though this is an exception, it is one that rather confirms the rule; for though shells are vital *products*, no vital *process* goes on in their substance.

Crystals have a limit of size: Every crystallized species, as well as every organic species, has an approximate limit of growth, and consequently a specific size, which is seldom exceeded. In crystals this is not nearly so definite as in the higher orders of organisms; but it is quite as definite as in such low organisms as lichens.

are hard: A crystal is generally harder and more brittle than the same substance when in the non-crystalline state. In this crystals are contrasted with organisms, the substance of which is generally soft, and is always so in those parts of the organism in which growth, or any other vital process, is going on with greatest rapidity.

imperme-able by water: The substance of crystals is impermeable by water. This is true even of those crystals the substance of which is soluble in water, such as common salt: their substance

cannot be permeated by water so long as it retains the
crystalline structure. In this respect, also, crystals are
contrasted with organisms; for the substances that compose
organisms are always in some degree permeable by water.

On this depends the fundamental difference between the
mode of growth of crystals and of organisms. Crystals
grow by addition of substance at the surface, and at the grow at
surface only: organisms, on the contrary, both animal the surface only:
and vegetable, absorb into their interior the nutritive
materials that are to be added to their substance. In
other words, crystals grow by superficial accretion, organ-
isms by interstitial accretion.

Closely connected with the last-mentioned is another
difference, which also is a fundamental one. A crystal is
in a state of perfect molecular immobility: its molecules are mole-
cannot acquire mobility without the crystalline structure cularly immobile.
being destroyed. In an organism, on the contrary, a cer- Contrast
tain degree of molecular mobility is the first condition of of organ-
isms.
life: it is constantly excreting matter, while other matter is
brought in from without to supply the loss. This double
process goes on with most rapidity in those organisms
where the life is most energetic; that is to say, in warm-
blooded animals.

I have now stated the chief among what may be called
the physiological resemblances and differences between
crystals and organisms. Before I go on to their morpho-
logical resemblances and differences, it will be necessary
to give a brief account of the morphological, or formative,
principles of crystallization; of the optical properties of
crystals, which stand in close connexion with their forms;
and of the classes, or systems, of crystals.

For every crystalline species three lines may be found
which stand in a simpler geometrical relation than any
other to all the forms which are possible in the species.
These lines intersect in a point within the crystal. They
are called the crystallographic axes, or simply the axes. Crystallo-
They are never all in the same plane, and they all may be at graphic axes.
right angles to each other. The angles of their intersection
are constant "crystallographic elements" for the species.

If any face is produced till it cuts the three axes, the portions of the axes intercepted between the point where they intersect each other and the produced faces are called Intercepts. the intercepts of that face. For every crystalline species, certain faces may be found, the relations of which to the axes are simpler than those of any other faces that are possible in the species. The intercepts of these faces are Para-meters: called the parameters of the species, or, to speak more accurately, the parameters are the numerical ratios between the intercepts of these faces. The parameters are constant for the species.

In many cases two, or all, of the three parameters are equal. But when the parameters are not equal, they do their not stand in any simple numerical ratios to each other. ratios. In topaz,[1] for instance, the parameters are approximately 1, 0·5284, and 0·47698.

Ratios of It is a universal and very remarkable law of crystal-intercepts lography, that the three intercepts of any face which is to para-meters. possible in any species, stand to each other in ratios which are either those of the parameters of the species or else simple multiples or submultiples of the parameters. When a face is parallel to an axis, as occurs for instance in the cube, the intercept of that face on that axis is infinite. In Miller's Professor Miller's crystallographic notation, instead of the notation. ratios of the intercepts to the parameters, the reciprocals of the ratios are taken as the indices of any given face. The reciprocal of infinity is 0. In this notation, when the angles at which the axes intersect each other, and the ratios of the parameters are known, the relation of any face to the three axes may be expressed by the three indices of the face ; and these are always capable of being written as whole numbers, counting 0 as a whole number. An index is seldom higher than 6. Similar and opposite faces have the same indices with opposite algebraic signs. Topaz. In topaz, for instance, there may be a face with the indices 4, 2, 3 ; and as the values of the parameters of topaz, as stated above, are 1, 0·5284, and 0·47698, the

[1] Mr. Maskelyne's Lecture on the Crystal Molecule as examined by Light, at the Royal Institution, 1st April, 1859.

intercepts of such a face stand to each other in the ratios of $\frac{1}{4}$, $\frac{0\cdot5284}{2}$ and $\frac{0\cdot4698}{3}$.

In practice, the angles that the faces of a crystal make on each other are measured by means of Wollaston's reflecting goniometer, and the crystallographic elements are then mathematically calculated from these.

When the angles at which the axes of any species intersect each other, and the numerical values of the parameters, are known, all the crystallographic elements of the species are known: and any form is a possible one in the species (though it may not have been actually found) in which the angles of the faces on each other are such as to fulfil those conditions. *Crystallographic elements.*

Consequently, two kinds of variation of form occur within the limits of the same species. The magnitude of the faces is subject to no law: and this variability, of course, gives rise to great variability of form. If the typical form of a species, for instance, is cubic, the actual form of any specimen of the species may be that of a square or rectangular prism; and from such a specimen it will be impossible to tell what the values of the parameters are. But if there are "secondary faces" cutting off the edges or angles formed by the meeting of the primary ones, the values of the parameters may be calculated from the angles made by the secondary faces on the primary ones. *Variations of form,*

The kind of variability of form just described may be regarded as analogous to the irregular variability of the forms of such low organisms as lichens. But besides this irregular variability, many species are regularly variable, presenting distinct geometrical forms, of which however the crystallographic elements are the same. In crystals of the cubic system, for instance, the three axes are all at right angles, and the three parameters are all equal; these are the simplest of all possible crystallographic elements; and in this system the cube, the regular octohedron, the rhombic dodecahedron, and some others, are all found. Combined forms are also found, such as cubes with angles truncated by octahedral faces, octahedra with angles *irregular* *and regular.*

Secondary truncated by cubic faces, and cubes with edges truncated
planes.   by dodecahedral faces ; and other instances of the occur-
            rence of secondary planes on the angles or edges of the
Transi-   primary forms.   Gradations between two of the primary
tional   forms of the same species, as for instance between the
forms.   cube and the octahedron, are possible through these com-
            bined forms.   But gradation between the angles of any
            two faces on each other is not possible : for, as already
            stated, the intercept of any face on any axis stands in a
            simple ratio to the parameter of that axis ; and were there
            indefinite gradation, they would have to pass through
            complex ratios.

Analogy   The existence of different forms within the limits of
with
organisms. the same crystalline species may perhaps be remotely
            compared to the existence of those different forms within
            the limits of the same organic species which are related
            to each other as male and female, as larva and perfect
            form, and in other ways of which I cannot now speak
            particularly.

Law of   In normally formed crystals, every face has a similar
symmetry. face opposite to it ; and not only opposite to it, but in
            every position where a face is possible that is similarly
            situated with respect to similar axes.   Similar faces, in
            crystallography, are those which are similar in relation to
            similar axes, though they may not be similar in size or
            form : and similar axes are those which are inclined to the
            other axes at equal angles, and the parameters measured
            on which are equal.

               Crystals that present all the faces required by the law
            of symmetry just stated are called holohedral crystals.
            But in many cases only half the faces of a holohedral
            form, or half of some particular set of similar faces, are
            presented, the alternate ones being left out.   Such forms
Hemi-   are called hemihedral ; the tetrahedron, for instance, is
hedrism.   the hemihedral form of the octahedron.   There is no
            instance of anything like hemihedrism among organisms.

               Another way in which crystals deviate from typical
Hemi-   symmetry is by the production of hemimorphic forms.
morphism. In these the two extremities of the crystal are of different

forms, having unlike sets of faces, but within the limits of the same species, (that is to say, having the same crystallographic elements,) so that the two halves of the crystal seem as if they belonged to two different crystals. Hemihedrism and hemimorphism are characteristic of particular species.

Hemimorphism, which is occasional among crystals, is all but universal among organisms. Among plants and sponges there is a difference between the root and the upper part; and among animals generally, between the two ends of the alimentary canal.

Crystalline growth is controlled in a very remark- *Crystals* able way by the laws of symmetry. Crystals have a *repair in-* power comparable, or rather identical, at least in its effects, *juries.* with the power of organisms to repair injuries. Lavalle has found[1] that if a crystal of alum is placed in pure water till its edges and angles are dissolved away, and then put into a solution of alum, the edges and angles will form again. He also found that if one of the angles is cut off such a crystal, and the crystal put into the solution lying on the cut-off angle, so as to prevent that angle from forming again, a corresponding truncation will form, as the crystal grows, on the opposite angle.

Crystalline formation is also dependent in a very *Forms of* remarkable way on the medium in which it takes place: *crystals are* and I intend farther on to show reason for believing that *by the me-* the same is true of some of the lower tribes of organisms. *dium they* Beudant has found that common salt crystallizing from *in.* pure water forms cubes, but if the water contains a little boracic acid the angles of the cubes are truncated. And the Rev. E. Craig has found that carbonate of copper, crystallizing from a solution containing sulphuric acid, forms hexagonal tabular prisms; but if a little ammonia is added, the form changes to that of a long rectangular prism with secondary planes on the angles. If a little more ammonia is added, several varieties of rhombic octahedra appear; if a little nitric acid is added, the

[1] My authority for the statements in this and the following paragraph is Dana's Mineralogy, vol. i. p. 138.

rectangular prism appears again. The changes take place not by the addition of new crystals, but by changing the growth of the original ones.

Polarisation.   Most crystals, except those of metals and their alloys, are transparent; and most transparent crystals polarise light.

In what follows, I take the wave theory of light as proved : and it results from that theory that transparency, or the power of transmitting light, depends on optical elasticity, and that polarisation is caused by the optical elasticity being unequal in different directions.[1] It has been proved by mathematical reasoning on the laws of the propagation of luminous waves through media of unequal elasticity in different directions (or, as they may be called for brevity, unequally elastic media), that in every such medium there are three directions, at right angles to each other, in which the elastic force on which the propagation of the waves depends, reacts in the direction of the displacement. Two of these are also directions of maximum and minimum elasticity. These three directions are called the axes of elasticity, and are distinguished Axes of as axes of greatest, least, and mean elasticity. In polarising crystals whereof the three crystallographic axes are at right angles to each other, the axes of elasticity are parallel to the crystallographic axes; but this, of course, is not the case where the crystallographic axes are not at Ellipsoid right angles. If now an ellipsoid is constructed with its three axes proportional to the three axes of elasticity, those diameters of the ellipsoid at right angles to which the sections of the ellipsoid are circles will be directions in which light passing along them will not be polarised: . while light passing through the crystal in any other direction will be polarised. The directions of no polarisation Optic axes. are called optic axes. It follows from the properties of ellipsoids, that when the three axes of elasticity are all equal, the ellipsoid is a sphere; consequently all diameters

Axes of
elasticity.

Ellipsoid
of elas-
ticity.

Optic axes.

---

[1] My chief authorities for what follows on the optical properties of crystals are Dr. Lloyd, on the Wave Theory of Light ; Pereira's Lectures on Polarised Light; and Mr. Maskelyne's Lecture referred to above.

are equal, the optical elasticity is the same in all direc-
tions, and no polarisation takes place. Such is the case in Cubic
cubic crystals.   crystals.

When two of the axes of elasticity are equal, and the
third either greater or less, the ellipsoid is a spheroid of
rotation, having the axis that is unequal to the others as
its geometrical axis; the geometrical axis is the only axis
the sections at right angles to which are circles, and con-
sequently is the axis of no polarisation, or optic axis: a
ray passing in any other direction is polarised. Crystals Uniaxial
with these optical properties are called uniaxial.   crystals.

When all the three axes of elasticity are unequal, the
ellipsoid is not a spheroid of rotation: there are two
diameters, at right angles to which the sections are circles,
and which consequently are optic axes: these are not
coincident with any of the axes of elasticity, but are
in the same plane with the axes of greatest and least
elasticity. Crystals with these optical properties are called Biaxial
biaxial.   crystals.

It is necessary to bear in mind, that the axes of elasticity
and the optic axes are not *lines*, but *directions;* and that
the ellipsoid by which the optical structure of a crystal
is represented, though a true representation of facts, is
imaginary.

After this brief account of the geometrical and
optical properties of crystals, it is time to give some
account of their classification. The classes, or systems, of Systems of
crystals are distinguished from each other by the incli-   crystals.
nation of their axes, the equality or inequality of their
parameters, and their optical properties.

In the cubic system, the axes are at right angles and Cubic
the parameters equal: the optical elasticity is equal in all system.
directions, and is represented by a sphere; they have,
consequently, no polarising structure.

In the square prismatic system, the axes are at right Square
angles; two of the parameters are equal, but the third is prismatic
unequal to the other two. The axis of unequal parameter system.
is called the vertical axis; it is an axis of symmetry
for the crystal,—that is to say, the edges and angles

are arranged symmetrically around it, like the petals
and other parts of a regular, or circular, flower around
its axis.

Rhombo-
hedral
system.

In the rhombohedral system, the parameters are equal :
the axes are not at right angles, but each of them is in-
clined to the other two at the same angle. There is an
axis of symmetry, which however is not coincident with
any of the crystallographic axes, but equidistant from the
three ; it is parallel to the line connecting those two
opposite angles of the rhombohedron, which are similar to
each other and unlike all the rest.

Optical
properties.

In the square prismatic and rhombohedral systems, the
optical elasticity is represented by a spheroid of rotation,
with its axis parallel to the crystal's axis of symmetry :
this is consequently the optic axis, and is the same in
position for rays of all colours.[1] But for different colours
it is generally, though not in all cases, different in mag-
nitude ; the physical interpretation of which is, that the
amount of dispersion or angular separation of the rays
in double refraction is different for rays of different
colours.

Right
prismatic
system.

In the right prismatic system, the axes are all at right
angles, and the parameters unequal. The axes of elasticity
are parallel to the crystallographic axes, and, like the
parameters, are all unequal : consequently the optical
elasticity is represented by an ellipsoid which is not a
spheroid of rotation, and there are two optic axes, neither
of which coincides with any axis of elasticity. The axes
of elasticity are the same in position for all colours, but
different in relative magnitude : as a consequence of which

---

[1] We must apply some qualification to the statements in the text, that
cubic crystals have no polarising structure, and that square prismatic and
rhombohedral ones are uniaxial. Sir David Brewster has found that many
cubic crystals have traces of polarising structure (Philosophical Transac-
tions, vol. ciii.) ; and Professor Breithaupt has found most square, prismatic
and rhombohedral crystals to be biaxial ; but he is of opinion that this is
due to want of symmetry in the crystals, and that the statements in the text
(which are those made in all works on mineralogy) are true of perfectly
formed specimens, which, however, are rare in nature. (Philosophical
Magazine, June 1860.)

the position of the optic axes is different for different colours.

In the oblique systems, the parameters are unequal, and so are the axes of elasticity.[1]

In the singly oblique system, two of the axes are in- Singly oblique system. clined to each other (*i.e.* are not at right angles); the third is at right angles to the other two. To this third, or rectangular crystallographic axis, one of the axes of elasticity is parallel; but the other two axes of elasticity are not parallel to the remaining crystallographic axes, and are different in position for light of different colours: and, of course, the optic axes are also different in position for different colours.

In the doubly oblique system,[2] one of the axes is at Doubly oblique system. right angles to the second, and inclined to the third; the second and third are inclined to each other. Its optical properties, so far as I know, have not been described, but they are no doubt similar to those of the system to be next described.

In the anorthic system, none of the crystallographic Anorthic system. axes are at right angles to each other: the axes of elasticity are not parallel to them, and are different for rays of different colours, as are also the optic axes.

Crystals are classified on much the same principles as organisms. Among both, the species group themselves into genera, and the genera into classes or systems; among both there are varieties, which sometimes form a gradation between species: and among both, species or genera are found that form a gradation between classes. As already stated,[3] crystalline varieties are due to slight Varieties. differences in chemical composition: those which form a gradation from one species to another are due to the presence of plesiomorphous substances.

---

[1] In strictness of language, the rhombohedral system is an oblique one; but it is not usual to call it so, as in its general properties it has more resemblance to the rectangular systems.

[2] Only one species of this system has been described: it has been found by Naumann as the crystallizing form of an artificial salt. (Dana's Mineralogy.)

[3] P. 69.

Boracite.

The most remarkable instance of a species intermediate between classes is that of boracite, which is geometrically one of the cubic system, but has the optical properties of a rhombohedral crystal: its optic axis is parallel to one of the diagonals of the cube.[1] There are also several instances of plesiomorphism between the cubic and rhombohedral systems.

Intermediate forms, showing the true affinities of the rhombohedral system.

In organic classification, the discovery of intermediate groups is often of great importance for the purpose of giving an insight into the true affinities of organisms and the true homologies of their parts. It is the same in crystalline classification. An important · question, on which authorities are divided, is, what are the true crystallographic axes and the true fundamental form of the rhombohedral system. Those whom I have followed regard the fundamental form as the rhombohedron, and the true crystallographic axes as those lines which connect the centres of its opposite faces. Others call the system hexagonal instead of rhombohedral: they regard the hexagonal prism as the fundamental form, and the axis of symmetry of that form as the vertical axis; and they draw three horizontal axes in the same plane, at right angles to the vertical axis. The rhombohedron and the hexagonal prism are forms that are both found in the system; both, indeed, are found in the one species of calc-spar: and either may be derived from the other, in strict accordance with the geometrical laws of crystallography, by supposing the angles of the primary form to be truncated by secondary planes.[2]

---

[1] Pereira's Lecture on Polarised Light, p. 194.

[2] Brooke and Miller adopt the rhombohedral theory; Dana, the hexagonal one.

It may be said this is only a question of words, since either theory gives true mathematical results. I believe, however, that an inaccurate classification always tends to obscure knowledge.

In the text I have in some degree sacrificed accuracy to clearness and intelligibility. There is not strictly any such thing as a fundamental form; the only constant crystallographic elements are the inclinations of the axes, and the ratios of the parameters. In the cubic system, for instance, the cube and the octohedron may with equal accuracy be regarded as fundamental; and that system is called octohedral as often as cubic.

The hexagonal theory has the advantage of making the axis of symmetry, to which the optic axis also is parallel, to be a crystallographic axis.[1] But I believe the rhombohedral theory to be the sound one : partly because it makes no exception to the law that every crystal has three axes, and partly because, by referring the cube and the rhombohedron to homologous axes, it recognises the homology between the cubic and the rhombohedral systems, and the possibility of gradational forms between the two ; while the hexagonal theory obscures these truths, by referring the cube and the rhombohedron to axes which are not homologous.

Among organisms the true affinities and homologies are not always the apparent ones : one organism may often be said to be disguised in the likeness of another. The whales, for instance, are mammals in the likeness of fishes: the chitons are molluscs in the likeness of annelids. The same occurs in at least one known instance among crystals. The crystals of Herschellite have the form of hexagonal prisms, which were formerly referred without hesitation to the hexagonal or rhombohedral system. But it has been found by examination with polarised light, by which the optical properties of crystals are tested, that the hexagonal crystal of Herschellite really consists of six triangular crystals, belonging to the right prismatic system; though they are not recognisable as such by their form, which is altered in consequence of their being thus united.[2] *Affinities, true and apparent.*

Herschellite.

This brings us to the curious and beautiful subject of compound crystals. These have been compared to animal monstrosities ; but this is an error, or rather a stupidity, which has arisen from comparing crystals with the higher organisms instead of with the lower ones. The true analogy of such crystals as Herschellite is to flowers. *Compound crystals:*

I prefer, however, to call it cubic, and so to keep before the mind's eye the homology betwen the axes of the cubic, rhombohedral, and prismatic systems.

[1] See p. 71 for the meaning of this expression.
[2] Dr. Von Lang in Philosophical Magazine, December 1864.

The occurrence of compound crystals is in some species only occasional, but in others, as in Herschellite, it is general.

Branching, Both crystalline and organic structures sometimes assume a branching form; as for instance in those combinations of ice-crystals called frost-work; in sea-weeds, in coral, and in trees. But this is characteristic of imperfect crystals and of low organisms. The ice-crystals that constitute frost-work do not present perfect crystalline forms, as is shown by their curved outlines. Sea-weeds and corals are low organisms; and though a tree is not so, the trunk and branches are less highly organized than the leaves and flowers.

Chain-like, Another mode of combination that belongs to comparatively low organisms, and, I believe, to imperfect crystals, is by a chain-like succession, as in the successive similar segments of worms, and in those molluscoids called Salpæ.

Double, "Twin crystals," or crystals found in pairs united by two of their planes, are common, and are characteristic of some species. Such a binary combination is not common among organisms, but it occurs in the calyx leaves of the poppy, and of that beautiful flower the dielytra.

Circular. Many crystals unite circularly round an axis. I have already mentioned Herschellite as an instance of this.

Snow. Snow consists of minute six-rayed stars, or, what is as good a description, six-leaved flowers, each of which is composed of six rhombohedral crystals. And there is

Staurolite. a species of right prismatic crystal called Staurolite, from the tendency of its crystals to unite into groups of four, shaped like a cross. The resemblance of flowers

Resem-
blance to
flowers. to such crystalline forms as these is obvious: and it is a resemblance not only of form but of structure; for flowers consist of modified leaves arranged round an axis.

Interpene-
trating
crystals. Tetrahedral crystals of species belonging to the cubic system are sometimes found interpenetrating each other, in such a way that the middle part belongs equally to both. These cannot be compared to any normally compound organisms: they can only be compared to those monstrosities in which, for instance, one body equally belongs to two heads.

All crystals are of the same *chemical constitution* throughout: differing in this from organisms, in all of which, except the lowest, there is a difference of composition in the different parts. But in some crystals the *structure* is not the same throughout. Sir David Brewster has described[1] specimens of Apophyllite, a square prismatic crystal, consisting of crystals symmetrically united together, some of which, when examined by polarised light, prove to be uniaxial, and some biaxial: the optical character of each single crystal being in some way determined by its position in the compound one. One of the simpler forms described has a horizontal section like this: the central square prism being uniaxial, and the surrounding irregular ones biaxial. No difference of structure is discernible by any other means, and no joinings between the prisms are to be perceived.

Tesselated Apophyllite.
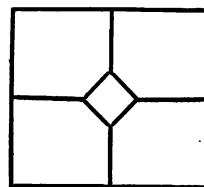
Different parts of a crystal of Analcime have different optical structure. Analcime is a cubic crystal; but, unlike other cubic crystals, it has a very decided polarising structure: and, unlike all other known crystals whatever, it consists of parts that have different optical properties, not sharply separated as in the tesselated Apophyllites described above, but graduating into each other. If the cube of Analcime be dissected by planes passing through the twelve diagonals of its six faces, these planes will be found to be places of no polarisation. Every other part of the crystal polarises with a force proportional to the square of its distance from the nearest of those planes.[2]

Analcime.

All perfect crystals have cleavage planes: that is to say, directions in which they split more easily than in other directions. This property of course depends on molecular structure. Cleavage planes are always parallel to faces which are possible ones in the species, and consequently faces artificially or accidentally produced by cleavage belong to the crystalline species as truly as those with which the crystal was originally formed.

Cleavage.

[1] Edinb. Phil. Journ. vol. i.   [2] Pereira on Polarised Light, p. 194.

CHAPTER VIII.

THE CHEMISTRY OF LIFE.

Organisms contrasted with crystals.
I HAVE stated in the last chapter, that the substance of crystals is *hard* and *impermeable* by water; that they grow by *superficial* accretion only, and are in a state of perfect *molecular immobility*. The substance of organisms, on the contrary, is mostly *soft*, and *permeable* by water; they grow by *interstitial* accretion only, and a certain degree of *molecular mobility* is the first condition of their life.

Accretion and waste.
An organism, so long as it lives, is constantly losing substance by excretion, or waste; and is constantly receiving new substance from without by accretion. Growth is due to the excess of accretion over waste.

But the constant parting with old material and acquiring new material do not of themselves constitute life. If they did, a glacier would be alive; for it is constantly parting with material by melting away below, while it is as constantly acquiring new material in the shape of the snow that slides down to it above. The word *accretion* describes quite accurately the deposit of new material while a crystal is growing; but it is quite an inadequate description of the acquisition of new material by an organism. Only substances of peculiar chemical composition are capable of becoming part of the living organism. Consequently, only substances of suitable chemical constitution are capable of being food for organisms. So far, the organism resembles a crystal; for only the substance of which a crystal is formed, or some other substance which is isomorphous or plesiomorphous with it, can be added to the crystal and become part of its structure. But the difference consists

in this, that the new substance, in being deposited on the crystal, does not undergo any change whatever, except the change from the liquid to the solid state; while, on the contrary, no new substance can become part of an organism until it has undergone a certain transformation by the agency of the organism itself, which makes it similar in point of chemical constitution to the substance of the organism, and fit to become part of it. This process is what is called assimilation. Assimila-tion.

The statement, that a living organism is constantly losing substance by waste and acquiring other substance by *accretion*, though true, is thus shown to be inadequate; and we must enlarge it by saying, that the organism is constantly losing substance by waste, and acquiring new substance *which it transforms into its own substance* by *assimilation*. This double process of assimilation and waste is general among organisms, vegetable as well as animal; and it has been very generally regarded as the only characteristic which is common to them all:[1] but I shall have farther on to give reasons for believing that there are other characteristics which are equally common to all organisms whatever.

The substance of an organism consists of chemical compounds of high complexity, which are not found in the inorganic world, but are formed by the action of the organism itself on the food that is brought from without. This process of forming the substance of the organism by assimilating the food is always going on; and the opposite process of waste is always going on, consisting in chemical changes that transform the compounds of which the substance of the organism consists, into compounds of simpler chemical constitution, which are no longer capable of forming part of the organism, but are excreted.[2] Organic com-pounds:

[1] Comte (Positive Philosophy, Harriet Martineau's condensed translation, vol. i. p. 362) quotes with approbation De Blainville's definition of life as a "double interior motion, general and continuous, of composition and decomposition;" evidently meaning that life is a process of assimilation and waste.

[2] Even this statement may need some qualification. No doubt all organisms grow by assimilation, but it does not appear certain that all the

Every one knows that waste is constantly going on from animals. It is not so easy to prove that the same is true of vegetables, but it has been ascertained that vegetables, as well as animals, are constantly giving off carbonic acid,[1] which can only come from the waste of their substance.

is the distinction between them and inorganic ones absolute?   The statement made above, that the compounds which compose an organism can be formed nowhere but in the organism, will probably be questioned; indeed, many of my readers will probably think it is contradicted by those wonderful discoveries of late years in organic chemistry, which have made it possible to form many of the so-called organic compounds from their elements by the inorganic processes of the laboratory. The opinion appears to have gained ground, that there is no absolute distinction between organic and inorganic products, but that with increasing chemical knowledge we may hope to form in the laboratory every substance which we know as a product of vital action.

I believe it is.   I cannot, however, think so. The most characteristically organic, or vital, products are those of the albuminoid class; and I cannot think it possible that they can ever be formed by any chemistry except that of the organism of living vegetables. Animals cannot form them. All animals feed either on vegetables, or on other animals which have fed on vegetables; they receive the albuminoid compounds in their food; these undergo a process of assimilation in the animal's system, which makes them fit to be incorporated with its tissues.

If the albuminoid and other characteristically organic compounds could be formed by any inorganic chemistry, it would be possible for man and his domestic animals to

lowest organisms lose matter by waste. "In the process of putrefaction, the researches of Pasteur have shown that so far from oxygen being necessary to the life of the simple living beings concerned, there are certain forms of infusoria which not only pass their lives without oxygen, but are killed by its presence." (Beale's edition of Todd and Bowman's Physiology, p. 19.) What Pasteur here regards as infusoria must, I think, be rather vegetable than animal. But whether this is so or not, it is not easy to see how waste can go on in organisms that never come in contact with oxygen, and where, consequently, oxidation is impossible.

[1] Carpenter's Human Physiology, 6th edit. p. 8. It is from this edition I shall always quote.

obtain their food from chemical manufactories, and to be independent of the vegetable world; and this appears as far beyond possibility as it would be to create or destroy matter or energy by any physical process.

The truth on this subject appears to be, that the albuminoid class of substances, which are those which appear most essential to the vital processes of both animals and vegetables, can only be formed in, and by, an organism; and that those so-called organic products which have been made in the laboratory are not capable of forming part of any living tissue, but are only products of the decomposition of living tissue.[1] I do not say that they are all waste products. Urea, which was the first organic compound that was made in the laboratory, is no doubt a mere waste product. But this is not true of butyric ether, the flavouring matter of the pine-apple; amylic ether, the flavouring matter of the pear; and formic acid, which is produced by ants.[2] These have all been made in the laboratory, and yet they are not waste products: on the contrary, they are stored in the organism for purposes connected with its economy. But they are not capable of forming part of any living tissue. The truly organic compounds—those, I mean, which constitute the substances in which the vital processes go on—are *colloidal*, or gelatinous. Formic acid and the ethers, on the contrary, belong to the *crystalloidal*[3] class of substances, which may be solid and may be liquid, but cannot assume the intermediate gelatinous form; and though many of these, as for instance water, are necessary to life, they cannot become part of any living tissue—in a word, they cannot be *vitalised*—unless they enter into combination, and in so doing change their character.

[1] See Dr. Beale's edition of Todd and Bowman's Physiology, p. 9.

[2] See Quarterly Journal of Science, Jan. 1866, p. 36.

[3] I do not mean that they have been crystallized. But this is not the only test of crystalloidal nature. Only crystalloids have a strong flavour of any kind; and strong flavour is a characteristic of the substances mentioned in the text. This property is no doubt a result of their diffusibility in water, by reason of which they are able, when in solution, to come in contact with the extremities of the nerves of taste.

Life works I have expressed my opinion, that it is in the nature of
through things impossible for the most characteristically vital pro-
the chemi-
cal forces, ducts to be formed by any inorganic chemistry. I believe
they are formed by the action of the ordinary chemical
forces, modified and as it were guided by that of the vital
principle. Life, or the vital principle, works not by op-
posing nor by suspending the action of the physical and
chemical forces; on the contrary, it works through them.
The relation of life to the lower forces may be compared,
remotely but truly, to the relation of the mechanical
as an en- engineer to the steam-driven machinery that he constructs
gineer
through a and keeps at work; he does not set aside the properties
machine. of iron and the force of steam, but he avails himself of
them, and works through them to the production of effects
which the iron and the steam could not have produced
of themselves.

But even if it could be shown that the chemical actions
that go on in the organism are no other than what can be
imitated in the laboratory, it would still be certain that
life is not a mere resultant from any physical and chemical
The vital forces, and that consequently there must be a distinct vital
principle,
principle. By this expression I only mean that unknown
defined. and undiscoverable something, which the properties of
mere matter will not account for, and which constitutes
the differentia of living beings. To deny the existence of
a distinct vital principle, in this sense, is not so much
untrue as unmeaning. The formation of organic com-
pounds is the lowest of organic functions, and is indeed
characteristic of vegetables rather than of animals; above
it are the functions of organization, instinct, feeling, and
thought, which could not conceivably be resultants from
the ordinary properties of matter.

But we must carefully guard against the error of setting
up conceivableness or inconceivableness as a test of truth
in questions of fact; and we must be equally careful not
to make any assertion as to matter of fact, in the disguise
of the definition of a term. Notwithstanding what I have
Origin of said in the last paragraph, I freely admit that all questions
life a ques- concerning the origin of life are questions of fact, and

consequently must be solved, not by reasoning, but by tion for ex-
observation and experiment. It is one of the most im- periment.
portant of all scientific questions, whether the lowest forms
of life can be generated by a purely chemical process. The
preponderance of experimental evidence appears to be
against any such possibility, and to show that no organism
can be generated except from a previously existing organism.
But if it could be proved that the lowest forms of life can
be generated by a purely chemical process, still, as has been
lately remarked, this would bring us no nearer to any
absolute origin of life; for the chemical actions in which
the lowest forms of life are by some believed to originate,
consist in the decomposition of organic substances; so that
even this would be a case of the production of life under
conditions that require the previous existence of other
organisms.—For these reasons it appears most probable Life had
that life, like matter and energy, had its origin in no its origin
in creative
secondary cause, but in the direct action of creative power. power.

The question of the origin of species is a totally distinct Origin of
species a
question from that of the origin of life.   distinct

There is good reason to believe the most important question.
organic compounds to be thermo-positive.[1] "It has been Organic
com-
recently shown by Berthelot that by the hydration and pounds
dehydration of organic substances heat results. Thus thermo-
positive.
sugar, starch, and fatty matter by decomposition give rise
to increased development of heat; and when albuminoid
matters are hydrated and decomposed, or dehydrated and
caused to enter into composition, heat is set free altogether
independently of the process of oxidation."[2] It is, I think,
quite impossible to interpret these facts except by supposing
the substances in question to be thermo-positive; that is to
say, that they contain a charge of energy which is due to
their chemical constitution, and part with it when that con-
stitution is subverted. Thus, energy is taken up, and stored,
in the act of forming organic compounds; and this energy
is liberated again, whether as heat or in some other form,
in that chemical transformation which constitutes waste.

[1] See p. 50 for the meaning of this expression.
[2] Beale's edition of Todd and Bowman's Physiology, p. 137.

CHAPTER IX.

THE DYNAMICS OF LIFE.

Vegetables form organic compounds, which are oxidised by animals.

WE have seen in the last chapter that vegetables form the characteristically organic compounds ; these serve as the food of animals, and, after undergoing an assimilative change in their nutritive systems, become part of their tissues. The organic compounds afterwards undergo a change, chiefly consisting in oxidation, which totally alters their chemical character, and makes them incapable of any longer forming part of a living tissue, so that they are cast out as waste materials.

Their actions are opposite.

Animals feed on vegetables, and vegetables feed on inorganic matter. That is to say, vegetables derive the carbon, hydrogen, nitrogen, and oxygen, which are found variously combined in their substance, from the carbonic acid, water, and ammonia of the atmosphere. The assimilation to which an animal subjects its vegetable food before that food can become part of its tissues, though of course it is an all-important process for the purposes of life, effects but a very slight chemical change, and an exactly similar assimilative process is necessary when the food consists of the flesh of other animals.

Animal assimilation.

So that we may broadly say, that vegetables form the organic compounds out of the materials of the inorganic world, and animals give them back to the inorganic world again, in the form of waste material. Thus the relations of vegetables and of animals to matter are opposite.

Their relations to energy are also opposite. As already Opposite
dynamic
functions stated, the change that converts the substance of animal tissues into waste material essentially consists in oxida- of animals
and vege-
tables. tion, and oxidation always produces heat, or some equi- valent form of energy. The oxidation either of the food, or of the substance of the tissues that is passing away in waste, is the source of animal heat, and of the mechanical energy of animal motion. Animals thus *give out* energy to Animals
give out
energy. the organic world. The dynamical function of vegetables is the opposite of this. We have seen that they decompose water and carbonic acid. In the decomposition of water or carbonic acid, or any other product of combustion, a quantity of energy must be *taken up*, exactly equal to that Vegetables
take up
energy. which was given out when that product was formed by combustion ; and this is true whether the decomposition is effected by an inorganic process, or in the organism of a living vegetable. Thus, whatever quantity of energy *becomes actual*, as heat, from the oxidation of the substance or the food of an animal, and is *given out* in the radiation from the skin and in the heated breath ; the same energy must have *become potential*, and been *taken up*, when the vegetables on which that animal has fed[1] decomposed water and carbonic acid, and thereby fixed the combustible elements, the hydrogen and carbon of its food.

But in what form was this energy before it assumed this potential form ? for vegetables cannot create energy out of nothing, any more than can animals or machines.

It was in the form of radiance. It is usually said that Dynamic
action of the leaves and other green parts of vegetables decompose vegetables carbonic acid *under the stimulus* of light. But this is an in decom-
posing car- inaccurate expression: as well might we say, that the bonic acid. decomposing cell in electro-chemical experiments decom- poses water *under the stimulus* of the electric current. The decomposing cell, and the green leaf, are alike only the apparatus where the decomposition takes place ; the agent of the electric decomposition is the electric current, and the agent of the decomposition of the carbonic acid

---

[1] Or, in the case of a carnivorous animal, the vegetables on which its prey has fed.

(and, doubtless, water also) that is decomposed by the
green leaf is the sun's radiance that falls on it. As the
actual energy of the electric current is, in the act of
decomposing water, transformed into the potential energy
due to the mutual affinity of the separated oxygen and
hydrogen ; so the actual energy of the radiance that falls
on a leaf is, in the act of decomposing the carbonic acid,
transformed into the potential energy due to the mutual
affinity of the separated oxygen and carbon.

Contrast of vegetables and animals.
 Thus we see that vegetables transform energy from the
actual state of radiance to the potential state due to the
affinity of separated elements : and animals transform it
back again into the actual state, either as heat, or as
energy of muscular motion.

In a word, vegetables take up both matter and energy
from the inorganic world, and the animals that feed on the
vegetables give back the matter and the energy to the
inorganic world again.

Vegetable respiration.
 As already stated, however,[1] vegetables give out carbonic
acid, the formation of which is due to the slow oxidation
of their substance ; and it is, no doubt, in consequence of
this that, as ascertained by Dutrochet, their temperature
while living is slightly higher than that of the surrounding
air.[2] This is a process of respiration, essentially similar to
the respiration of animals. Respiration consists in giving
off the carbonic acid produced by the oxidation of the
substance or the food of the organism : and oxidation is
essentially combustion, and produces heat. Combustion
is only rapid oxidation.

Organisms transform
 It is no new discovery, but a familiar truth, that a
transformation of matter is, as we have seen in the

[1] P. 86.

[2] Carpenter's Comparative Physiology, 3d edit. p. 846. It is from this
edition that I shall always quote.

This fact shows that the energy which living vegetables transform,
exists previous to its transformation, not in the form of heat, but in that
of radiance. Were heat transformed and destroyed, healthy green plants
would be sources of cold ; but we have seen that the reverse of this is true.
The coolness of vegetation as contrasted with the heat of bare earth or rock,
in warm weather, is due to the fact that living plants radiate heat abun-
dantly, and also produce cold by the evaporation of water from their leaves.

last chapter, constantly going on in every living organism. matter and
But I believe it is equally true, that a transformation of energy.
energy is also constantly going on ; and I believe that any
account of the vital process contains only half the truth,
unless it gives as much emphasis to the fact of the trans-
formation of energy by the action of the organism, as to
the fact of the transformation of matter. In the present
state of science, indeed, this is almost self-evident; but it
could not be clearly seen until the laws of the conservation
of energy, and of the transformations of energy, were
understood. The principal relation of vegetables to energy Relation of
is, as already explained, that they transform the radiance vegetables
that falls on their leaves into the potential energy due to animals to
the decomposition of the carbonic acid which is separated energy.
into carbon and oxygen. And one important relation of Animals
animals to energy is that, as already explained, they pro- produce
duce heat by the oxidation of carbon, in their respiratory
organs and throughout their whole system.

But it is obvious that this is not the only mode in which
animals transform energy. They are producers of motion and
as well as| of heat; and one of the most characteristic motion.
peculiarities of the animal kingdom as contrasted with the
vegetable, is the possession of a special apparatus—the
nervo-muscular—of which the primary function is the
production of motion. But the production of motion does Motion in-
not depend on the presence of either nerves or muscles : dependent
there are animals of low organization, in which the micro- ture.
scope reveals no muscular structure, and indeed no struc-
ture at all, which have nevertheless the power of motion.
And the same appears to be true of the " ciliated cells " of
the higher animals.

Heat and motion are the principal forms of energy Animal
that animals produce, but not the only ones. The glow- motion,
worm, and some other insects, have a special apparatus for light, and
the production of light, and many of the simpler marine electricity:
animals are luminous.[1] And the torpedo, the gymnotus,

---

[1] Among the medusæ and mollusca the luminosity appears to be due
to a phosphorescent secretion, and, if so, cannot be regarded as a vital
phenomenon. But among the marine annelids, or worms, it does not

and a few other fishes, have a special apparatus for the production of electricity at will; the structure of which, according to Professor Owen, very much resembles that of the muscles.

their
origin

But motion, light, and electricity, as well as heat, can only be produced by the transformation of pre-existing forms of energy; and the usual statement is, that all the energy which animals transform and part with is due to the oxidation which, as we have seen, goes on within the organism. This statement however needs modification, for, as we have seen, the organic compounds, which undergo oxidation and decomposition in the organism, are thermo-positive;[1] and consequently energy is liberated in their decomposition, which no doubt becomes available for transformation into heat, muscular motive power, or any other form that may be needed for the purposes of the organism. But this we can say with perfect accuracy,

is che-
mical.

that all the energy that animals transform has a chemical source, either in oxidation, or in the decomposition of thermo-positive compounds.

Does the
animal
organism
store
energy?

The question now arises, whether the energy that animals part with in muscular action is obtained, by these chemical actions, at the very moment when it is wanted; or whether there is a stock of energy constantly kept in the body, in a peculiar form distinct from any chemical form, and capable of being drawn on for conversion into muscular motive power when wanted?

Illustra-
tion from
Arm-
strong's
Accumu-
lator.

This distinction may not be quite intelligible to readers who are not familiar with the subject of the trans-formations of energy; but it may be illustrated by the following example. When a steam-engine is at work in the usual way, the motive power that it exerts is all produced, by the combustion of the fuel in the furnace, at the very moment when it is wanted; and the steam-engine can do no more work in any given time than is due to the

appear in a steady glow, but in flashes or scintillations, which are produced by irritating the animal; and some of the smaller crustacea also emit light in little flashes. (Carpenter's Comparative Physiology, p. 841.)
[1] P. 89.

energy which is liberated in the combustion of the fuel
that is burned in the furnace during that time. But if
the steam-engine works in connexion with one of Arm-
strong's hydraulic accumulators,[1] energy, or motive power,
is stored in the accumulator; so that work may continue
to be done for some time after the steam is turned off or
the fire put out. The question I have asked is this:
Does the animal organism resemble the steam-engine
working without an accumulator, which can only transform
the motive power which is at that very instant liberated in
the chemical process of combustion? Or does it rather
resemble the steam-engine working with an accumulator,
which stores motive power in a form that can be drawn on
when wanted?

I believe there is conclusive evidence that the latter is Vital
the fact. I believe there is conclusive evidence that the energy.
living animal contains a variable quantity of a peculiar
form of static actual energy, which is capable of being
transformed when needed either into heat or into muscular
motive power. I propose to call this vital energy;[2]
and I regard it as a distinct form of actual energy, just
like heat, electricity, magnetism, or the energy of motion.
An animal, regarded as a motor apparatus, may thus be
compared to a steam-engine doing work with the assist-
ance of an accumulator. In both, energy is being con-
stantly obtained by the combustion of carbon (for the
oxidation that goes on in the lungs and throughout the
body is combustion, differing from that of a furnace only
in being slower); in both, the energy, when not at the
moment wanted to do work, passes into the static form.
In the steam-engine it passes into the static potential
energy due to the raised weight of the accumulator; in
the animal, into that form of static actual energy which
I propose to call vital energy. And in both, it is capable
of being used as motive power when wanted to do work.

[1] P. 21.

[2] It will be perceived that *vital energy* is by no means a synonymous
expression with *the vital principle*. If what I have endeavoured to
establish on the subject of vital energy is proved to demonstration, it still
leaves the mystery of the vital principle exactly where it was before.

But what is there in the organism to represent this vital energy? Heat and radiance consist in motion; magnetism and electricity, probably, in molecular tensions; but in what does vital energy consist?

Its nature inexplicable.

This question is at present impossible to answer, and perhaps must ever remain so. But the chemical forms of force are equally inexplicable. We cannot tell in what consists either the static potential energy that becomes actual in combustion or in the voltaic battery, or the actual energy that becomes static in the formation of peroxide of hydrogen, or any other thermo-positive compound.

I must now proceed to state the proofs of the existence of vital energy in a distinct static form.[1]

Of course I do not maintain that the whole of the energy due to the oxidation of the food, and of the waste materials of the body, is ever converted into vital energy. Probably by far the greater part of it, in all warm-blooded animals at least, is at once converted into heat, and used in keeping up the temperature of the body. It is a familiar fact, that whatever increases the activity of respiration, also increases the production of animal heat. But there are many phenomena of animal heat which are not capable of being thus accounted for. Though chemical action is the source of the heat as well as of the motor energy produced by the animal organism, no purely chemical theory will account for the local variations of temperature in the body.[2]

Muscular heat

Muscular action causes an increase of temperature in the acting muscle; and the increase is greater when the muscle is strained in a "dead pull" against something unyielding, than when it lifts a weight. This is a very interesting instance of the law of the *equivalence* of different forms of energy; the muscular energy which raises a

[1] The only author with whose work I am acquainted, that has distinctly asserted the existence of vital energy in a static form—or, in other words, asserted that the animal organism stores energy—is Dr. Norris, in his Report on Muscular Irritability (British Association, 1866, Nottingham). I had, however, thought out the whole theory of static vital energy independently.

[2] Paget, quoted in Carpenter's Human Physiology, p. 365.

weight is transformed into the potential energy due to the
raised weight, and if the same muscular energy is expended
without being able to raise a weight or do other external
work, it is transformed into heat.[1]   Normally, the increase
of temperature is not more than about 1° Fahr., and it is not
perhaps incredible that this should be due to the more
rapid chemical action that goes on in muscle when it is
in activity than when in repose.   This heightening of
chemical action in muscles during activity is proved by
the fact that lactic acid, which is a product of their oxida-
tion, is found in the muscles of animals that have been
violently convulsed, though it is not found in muscles in
their normal state.[2]   But though chemical action may
account for a rise of temperature in muscle to the extent
of 1° Fahr. it appears altogether inadequate to account
for a rise of the temperature of the body to $110\frac{3}{4}$° Fahr.,
which is more than ten degrees above its normal level;
and this has been observed in the convulsions of tetanus. in tetanus.
No conceivable increase in the rate of chemical action
would produce such a rise of temperature as this; and I
believe it must have been caused by the transformation of
a portion of the stock of vital energy into heat.

Another case of increased production of animal heat
which cannot be due to any increase in the rate of oxida-
tion or of any other chemical process, has been observed
in patients dying of yellow fever, when the temperature of Heat pro-
the body rose to the extent of 5° Fahr. in the first ten duced at
death;
minutes after death.   What proves, if proof were needed,
that the heat could not be from any chemical source, is
that the capillary circulation in those cases continued for
an appreciable time after death, showing that putrefaction
could not have set in; and this extraordinary production
of heat can, I think, only be explained by supposing that
the vital energy of the body was transformed into heat in
the act of dying.[3]

  [1] The following statements, where no other authority is given, are taken
from Carpenter's Human Physiology, chap. x.
  [2] Carpenter's Human Physiology, p. 677.
  [3] There is an experiment of the celebrated John Hunter which is

and during   Another proof that animals have a stock of vital energy
starvation. to draw on for conversion into heat when needed, is
afforded by the fact that starving animals are able for some
days to produce heat at a greater rate than the chemical
actions that go on in the body could supply.[1]   For some ·
days the temperature is kept very nearly up to its normal
level, and afterwards it falls very rapidly; and the imme-
diate cause of death is the depression of temperature.   It
is a familiar fact that starving animals lose substance, and
it is certain that the oxidation of the substance that dis-
appears helps to keep up the temperature; but it now
appears that there is more heat produced than this will
account for; and the excess can be, I think, due to no
cause except the transformation of vital energy.

The vital energy in the body is of course not. fixed but
fluctuating in quantity; it is expended by muscular
exertion, and restored again during rest, and especially
during sleep.[2]   Abundance of vital energy is probably the

probably a case of the same kind.   He put a bottle containing leeches
into a freezing mixture : a thermometer among the leeches sank to 31°;
it afterwards rose to 32°, and the leeches froze.   (Carpenter's Comparative
Physiology, p. 848.)   The thermometer rising when the leeches froze,
seems to show that their vital energy must have been transformed into
heat.

[1] " It has been experimentally found that in the ordinary life of an adult
mammal, the quantity of food necessary to keep the body in its normal
condition, is *nearly twice* that which would be required to supply the waste
of the organism, as measured by the total amount of excreta when food is
withheld."   (Dr. Carpenter, Quarterly Journal of Science, vol. i. p. 265.)

It follows from this, that animals from which food is withheld are able to
keep up their temperature, as starving animals do until they are near
death, at an expenditure of *little more than half* the material (as shown by
the amount of the waste of the body) that is consumed in well-fed animals.
I do not see any possible way of doing this, except by drawing on their
stock of vital energy for conversion into heat.

I presume that in the experiments referred to by Dr. Carpenter the
"excreta" include the carbon that passes away by the lungs.   Otherwise
the experiments prove nothing at all, at least on the present subject.·

[2] It is a general instinct among animals to keep themselves from
external cold during sleep; and this may be in order to prevent the energy
that they need for storing up in the muscular system, from being expended
in conversion into animal heat, and employed in merely keeping up the
temperature of the body.

cause of that feeling of buoyancy which makes action Buoyancy
more agreeable than rest; and deficiency of it is probably and
fatigue.
the cause of the sensation of fatigue. And perhaps, though
I only offer this as a suggestion, the immediate cause of Death from
death by fatigue may in some cases be the want of sufficient fatigue.
vital energy in the system to supply motive power for the
muscular work of the heart and lungs.

It is the function of the muscles to transform vital Relation
energy into motor energy; and it appears to be one of the of the
nervous
various functions of the nervous system to transform vital system to
energy into heat. We may say, indeed, that the primary animal
heat.
function of the whole nervo-muscular system, including the
electric apparatus of the torpedo and other electric fishes, ·
is to transform vital energy into other kinds of energy. To
this class of phenomena probably belongs the well-known
but little understood fact of the high temperature of Heat of
inflamed
inflamed parts. This cannot be due to any increase of parts
chemical action; for, contrary to what we might expect,
an examination of the blood that has passed through an
inflamed part shows that oxidation goes on not more but
less rapidly in an inflamed part than in a healthy one.[1]
But the increased sensitiveness of inflamed parts shows
that nervous action in them must be in some way
heightened; and this heightening of nervous action pro- due to
bably determines a conversion of vital energy into heat. nervous
action.
Sensation, however, is not what constitutes nervous action;
sensation is only a concomitant of nervous action, and not Insentient
action.
by any means an invariable concomitant. The nervous
system is primarily a part of the animal apparatus for the
transformation of energy; and it is scarcely possible to
doubt that all excitement of the nerves, whether accom- Nervous
action
panied by sensation or not, determines the transformation always
of part of the stock of vital energy into some other form causes
transfor-
of energy. If it is not transformed into motion, it is then mation of
probably transformed into heat. This is in accordance energy,
with the analogy of other vital actions; and, besides, there
is something of the nature of experimental evidence for
it. It is a familiar fact that severe pain often produces

---

[1] Beale's edition of Todd and Bowman's Physiology, p. 137.

involuntary convulsive struggles; and the stimulation of
sometimes into mo-tion, the motor nerves, unaccompanied by pain, is capable of
producing the same effect.[1] In such cases the vital energy
is transformed into motor energy. But vital energy is
also capable of being exhausted in a perceptible degree by
nervous excitement, even when there is no motor action;
as is shown by the fact that the sense of fatigue is pro-
duced by mental exertion, or by pain unaccompanied by
struggling, just as it is by muscular exertion. We should
probably be justified in concluding, even without more
sometimes into heat. direct evidence, that in such cases there must be a trans-
formation of vital energy into heat. But there is direct
Valen-tin's ex-periment. ·evidence of such transformation. Valentin has obtained a
rise of as much as $1\frac{1}{4}°$ centigrade in the temperature of the
sciatic plexus of a frog, by mechanical or electrical irrita-
tion of its spinal cord.[2] It is quite impossible to say how
far this was due to pain: or, we ought rather to say, how
far it was accompanied by pain; for the physical character
and results of nervous action appear to be exactly the same,
whether it is accompanied by sensation or not.

It is a remarkable proof of the dependence of nervous
action on physical changes, that mental exertion causes the
brain to lose phosphorus, which is found in the excreta.

I think I have given conclusive proof that nervous
action is capable of producing heat and raising the tem-
perature; and, conversely, a lowering of nervous action has
a tendency to depress the temperature. The paralysed
Paralysed limbs. limb of a patient is usually somewhat colder than the
healthy one. And a curious instance is on record, in which
a wound of the wrist, which must have affected a nerve,
produced partial insensibility in the forefinger, and lowered
its temperature 10° Fahr. below that of the thumb.[3] These
last two instances, however, only concern the local distri-

---

[1] As in those remarkable cases where the lower limbs have been deprived
of sensation and voluntary motion by injury to the spinal cord, and yet
have continued to respond, by convulsive kicks, to any such stimulus as
that of tickling the soles of the feet.

[2] Medico-Chirurgical Review, January 1864.

[3] Carpenter's Human Physiology, p. 738.

bution of heat in the body; but we have evidence that the
temperature of the whole body may be lowered by injury to
the nervous system. It has been observed by Sir Benjamin
Brodie, and by others who have repeated his experiments, Effect of
that when the spinal cord of a rabbit or other animal is cutting
the spinal
divided in the neck, and the action of the lungs (which cord.
otherwise would cease in consequence of the paralysis of
the nerves that supply their muscles) continued artificially,
so as to produce the normal quantity of carbonic acid, the
temperature of the body falls.   Now, we know that a
definite quantity of actual energy is due to the formation
of a definite quantity of carbonic acid by oxidation,
whether in the living organism or in a furnace: in the ex-
periment in question this energy does not appear as heat;
· what then becomes of it?   I believe it is transformed into
vital energy. I think the only possible interpretation of this
experiment is, that the energy which becomes actual in
the formation of carbonic acid by oxidation in the body, is
in part transformed, not at once into heat but into vital
energy, which the nervous system is capable of afterwards
transforming into heat.   Consequently, when the nervous
system is in great part paralysed by cutting the spinal
cord, the production of vital energy, which is a function of
the whole organism, goes on as before; but its transforma-
tion into heat, which is a function specially of the nervous
system, is hindered.

   I admit, however, that it is not generally a satisfactory
mode of reasoning, to say that a particular solution must
be true because it is the only possible one.   We demand,
and reasonably demand, more direct proof.   In this case
there is another experiment, which is the exact correlative
of Sir Benjamin Brodie's, and shows us what has become Experi-
of the energy in question.   Brown-Séquard weighted the mental
proof
hind legs of living frogs, and thus ascertained what weight that the
they were capable of raising when the muscles of the legs muscles
store
were excited to contract by pinching the toes: this weight energy.
was taken as the measure of the contractile force of the
muscles.   He then divided the spinal cords of the frogs,
and found that twenty-four hours after the operation the

force of their muscles, as measured by the weight they were able to raise, was twice as great as when they were uninjured.[1] This, I think, when taken together with Sir Benjamin Brodie's experiment, affords direct and conclusive proof that in an animal with divided spinal cord the vital energy accumulates in the muscles, where it manifests itself by the greatly increased force with which they contract; while in an animal with uninjured nervous system, nervous agency determines the transformation of the vital energy into either heat or motor energy, and does not permit it to accumulate in so great a degree.[2]

It needs no proof that all animals produce motor energy. Most of them move about, and even those which are rooted, like corals and sponges, have tentacles or cilia, which they move. And, as we have seen, there is good reason for believing that animals have the power of storing vital energy, which they can afterwards convert into motor energy or into heat.

Motive powers of vegetables.

It is not so easy to prove that all this is true of vegetables: nevertheless I believe it is also true of them. The motion of the germs of sea-weeds is the most remarkable instance of motion in the vegetable kingdom: they move so actively through the water that they have often been mistaken for microscopic animals. But some degree of motive power appears to be universal in the "germinal matter" of vegetables as well as of animals.

" The substance called protoplasm [3] exhibits changes of form, and other movements, which cannot be explained by

---

[1] Dr. Norris's Report on Muscular Irritability, referred to in a previous note. Dr. Norris thinks, as I do, that this experiment proves that the muscles have the power of storing energy (or force, as he calls it).

[2] It is perfectly safe thus to reason from one organic species to another, for the fundamental laws of life are the same in all. Of course, this principle must be applied with caution ; but as the frog and the rabbit agree in the general plan of the nervous system, and in having red blood-corpuscles, we are quite safe in assuming such an analogy between them as makes the two experiments comparable and parallel.

[3] Protoplasm is what Dr. Beale calls "germinal matter," and what I have called "unformed but formative material." The latter expression, however, is not suited to be a technical one, and I intend to call it "germinal matter." It is found in all living organisms whatever.

any physical property, or by any extraneous influences. These movements are most remarkably shown at times in the spaces of young cellular tissue. The movement termed rotation, or gyration, which is often seen in the contents of young cells, and which, in some form or other, is probably of general occurrence, may depend on the contractility[1] of protoplasm. They are said by those who have studied them to present a close resemblance to those of Amœba[2] and its allies. No one has yet shown a distinction of importance between protoplasm of the vegetable and sarcode of the animal kingdom. But there are other movements in plants, the cause of which is less equivocal. Such movements are not confined to the lowest plants, as the Oscillatoriæ, but are met with among the most highly organized members of the vegetable kingdom. The movements of sensitive plants, various species of Mimosa, of Dionæa muscipula,[3] of certain tropical species of Desmodium, of the stamens of Barberry, &c. can be referred only to vital contractility of certain of their tissues. Whatever obscurity may hang over these, let it be remarked that there is the same evidence of the nature of this vital contractility in plants as in animals. It is dependent on life, and not, like any physical property, retained so long as the structure itself is not destroyed. So, also, these movements either occur spontaneously, or may be excited by various stimuli—touch for example. If those motions depended upon elasticity, or hygroscopic changes, or any other physical cause which elsewhere operates, how could stimuli act to produce them? Moreover, they appear to be governed by the same laws that regulate their action in the animal kingdom. Their energy varies with the vigour of the plant. *Excessive exercise produces exhaustion, but the power is restored during subsequent repose.* This evidence, thus clear and satisfactory, receives a remarkable

---

[1] *Contractility* is not a good word. What is meant is only the tendency to spontaneous motion.

[2] The amœba is an animal, and one of the simplest known, being a minute gelatinous mass without structure.

[3] Familiarly called "Venus's fly-trap," from the way in which the leaves spontaneously close on flies and crush them.

and most interesting confirmation from the effects produced by the vapour of chloroform." [1]

Vegetables probably store vital energy.

I have italicised a passage in the foregoing extract, in order to direct attention to the fact that the motive powers of plants, like those of animals, are subject to the law of exhaustion by exercise and renewal during repose. This appears to afford a presumption, though it would be too much to say that it amounts to proof, that plants, as well as animals, accumulate a store of vital energy which is capable of transformation into motor energy when needed.

Relation of organisms to energy and to matter.

I believe we may consequently state, with very strong probability, that the relation of organisms to energy is parallel to their relation to matter. As an organism is constantly acquiring matter, which it transforms by assimilation into its own substance, so it is also constantly acquiring energy from the chemical actions that go on within its body, and transforming it into vital energy.

Energy is assimilated.

This process may indeed be called the *assimilation of energy ;*—energy, like matter, is transformed by the action of the organism into the peculiar form which the organism needs ;—and this is the definition of assimilation. And as an organism is constantly parting with matter, which undergoes chemical transformation that unfits it for continuing any longer to form part of the organism, so it is also constantly parting with energy, which is transformed into inorganic forms (I mean, forms that may exist independently of vital agency) ; generally into heat or energy of motion : in the case of electric fishes, into electricity ; in the case of luminous insects, into radiance.

We may consequently make the following general statement.

General statement.

An organism consists of a mass of peculiar chemical compounds of high complexity, and contains a charge of a peculiar kind of static actual energy. It is constantly transforming both matter and energy, by assimilation, into those peculiar forms : and is as constantly parting with

[1] From a lecture " On Motion in Plants and Animals," delivered at the Royal Institution on 14th March, 1862, by William Scovell Savory, F.R.S. See also Beale's edition of Todd and Bowman's Physiology, pp. 33, 99.

matter and energy, which are transformed into forms that
are no longer capable of remaining in the organism. These
relations of the organism to matter and energy constitute,
I believe, the differentia of life; and death consists in Death
the organism losing that peculiar power of controlling the
action of the chemical and physical forces in virtue of
which it transforms and assimilates matter and energy.

When death has taken place—or, in other words, when followed
the controlling vital principle has ceased to act—the by chemi-
cal trans-
chemical forces begin to act according to their own ordi- forma-
nary laws, and decay or putrefaction may result, as cir- tions.
cumstances determine. In many cases, indeed, where
death takes place slowly, a change of the nature of putres-
cence begins before life is extinct.[1] It would be altogether Chemical
inaccurate to say that the action of the vital principle action
during
during life suspends the action of the ordinary chemical life.
forces ; on the contrary, the process of oxidation, causing
the transformation of organic compounds into inorganic
ones, probably goes on more rapidly in the body of a
warm-blooded animal during life than it does in the same
during the process of decay after death. But of course
the waste is balanced by assimilation of food in the living
animal, and not in the dead one. Vitality, I say, does
not suspend, but directs and controls, the actions of the
physical and chemical forces, producing results through
them which they could not have produced of themselves.

I have already stated that I believe organisms have a
relation to energy, parallel to their relation to matter. We
have seen that as a result of death the chemical forces,
being freed from vital control, act according to their own
ordinary laws, and effect the transformation of the organic
chemical compounds into inorganic ones. In a similar Transfor-
way, death, as I believe, effects a transformation of vital mation or
vital
energy into some ordinary inorganic form of energy. I energy in
have mentioned an instance in which the vital energy death
appears to have been transformed into heat in the act of
dying. But its transformation into motor energy is perhaps
a commoner case. This is, I believe, the *rationale* of those

[1] See Carpenter's Human Physiology, p. 57.

convulsive struggles that often accompany death, and which are usually attributed to pain, though this is not by any means invariably true.

and in disease.   Disease appears sometimes to effect in part the transformation of energy which death effects totally. Inflammation is a diseased state, and, as we have seen, in inflamed parts there appears to be an unusually rapid transformation of vital energy into heat. The rise of temperature in tetanus is another case of the same transformation, though the manner in which it is effected is probably very different.

Analogy of life to magnetism.   We may compare the charge of static actual energy, which, as I believe, every living organism contains, to the charge of static actual energy, which, as I think I have shown, constitutes magnetisation. As only some substances, all of which are metallic, are capable of being magnetised,[1] so it is only some substances, all of which are highly complex compounds of the albuminoid class, that are capable of being vitalized: and as magnetised iron is able to communicate magnetism to other iron, so vitalized matter is able to vitalize other matter of suitable chemical constitution which has become the food of an organism. Thus the laws of magnetism resemble, and as it were prefigure, those of vital energy, as the laws of crystallization resemble, and as it were prefigure, those of organization. But an organism differs from both a crystal and a magnet in this, that so long as the organism lives it is constantly assimilating, and again parting with, both matter and energy.

Summary.   The most important conclusions of this chapter may be thus summed up :—

Organisms assimilate, store, and finally transform and part with, energy as well as matter. The primary function of the nervo-muscular system of animals is to effect the

---

[1] Faraday has shown that oxygen is magnetic, but I do not think this implies that gaseous oxygen is capable of being magnetised. Magnetisation, as Faraday has shown, implies lines of force in definite directions, such as, I think, can only be due to the molecular tensions of solid bodies. See note to Chapter III.

final transformation of vital energy into inorganic forms of energy, especially into motion, in many cases into heat, sometimes into light or electricity. Muscular action transforms vital energy generally into motion, nervous action generally into heat. The muscles have the power of storing energy, in a peculiar static form, for future transformation. At death all the vital energy that was stored in the organism is transformed into inorganic forms: always, probably, into either heat or motion.

I am perfectly well aware that in this chapter I have not given a full account of the relation of energy to the various vital processes. But it is probably impossible to do so as yet. There appears to be a demand for energy *Depend-* in the form of heat, and probably a transformation of it, *ence of de-velopment* in the process of organic development. Heat, as already *on heat.* stated, appears to be a concomitant of vegetable as well as of animal life generally: and heat is produced in unusual abundance in the act of flowering,[1] and again in the germination of the seed. Its source in these cases is oxidation: this is proved, if proof were needed, by the production of carbonic acid: and its purpose, no doubt, is in some way to promote the transformations that take place in the acts of flowering and germination. Animal development also depends in some way on temperature: this, as every one knows, is true of the hatching of eggs, and it is equally true of the final metamorphosis of the insect.[2] It is a case of the same law, that the triton, or water-newt, which has a remarkable power of reproducing lost limbs, can only do so at a higher temperature than that which is necessary for its health.[3] It is scarcely possible to doubt *Transfor-mation of* that, in every act of organic development, there is *some* *energy in* transformation of energy, though we cannot yet say *what* *organic* transformation. Perhaps a charge of energy is taken up *develop-ment.*

[1] Adolphe Brogniart found the flower of the Arum cordifolium 20° of temperature above the surrounding air. (Carpenter's Comparative Physiology, p. 846.) It is not stated whether the degrees are centigrade or Fahrenheit's. 20° C. = 36° F.

[2] Carpenter's Comparative Physiology, p. 849.

[3] Ibid. p. 65, quoted from Mr. Higginbottom: Proceedings of Royal Society, 18th March, 1847.

and becomes static, in the act of unorganized material acquiring organization.[1]

Energy of life depends on the supply of oxygen. Vital processes go on with the greatest energy where oxidation is most rapid. This is partly, no doubt, because oxidation yields the necessary supply of heat and other forms of energy: partly also, because the waste, or what may be called the wearing out, of the tissues of the organism goes on most rapidly where vital processes are most energetic: and this will soon be checked if there is not a supply of oxygen to transform the organic compounds into freely soluble compounds, which can be easily removed from the system. It is, no doubt, in consequence **The most highly organized plants and animals are air-breathers.** of these two causes that air-breathing animals and air-breathing plants are in general, and on the average, of much higher organization than water-breathing ones, and that air-breathing animals have a more active and energetic life, for air contains a much more abundant supply of free oxygen than water. Warm-blooded animals, which stand at the head of the whole animal kingdom, are without exception air-breathers: and, among vegetables, most of the water-breathing kinds are flowerless, and, as such, inferior to the flowering ones in organization. It is no exception to this, but rather a confirmation of it, that many flowering plants, such as the water-lilies, though rooted under water, raise their flowers and part of their leaves into the air, in order no doubt to enable them to **Larva and perfect form.** obtain the oxygen they need. It belongs to this class of facts that there are many instances, among both insects and batrachians (frogs, newts, and similar animals), in which the larva is a water-breather and the perfect form an air-breather; but not a single instance, I believe, of the converse: for the perfect form in those two classes is always more highly organized than the larva. It is indeed the general law of animal metamorphosis, though subject to some remarkable exceptions, that the mature form is more highly organized than the larva.

[1] See chap. i. of Carpenter's Human Physiology.

NOTE.

ON THE RELATION OF MUSCULAR ACTION TO HEAT.

WE have seen that in muscular contraction heat is produced; and this I believe to be, in part, transformed vital energy. (I say *in part*, because I have no doubt that it is in part also due to the chemical action that takes place in the muscle at the moment.)

But it has been shown by careful experiments on frogs, that the first effect of muscular contraction is a slight cooling.[1] The most probable explanation of this fact appears to be, that the commencement of muscular action causes the conversion of a small quantity of heat into muscular motor energy. Cold pro-
duced in
muscular
action.

There is a remarkable fact in inorganic dynamics, which is nearly parallel to this.

If a joint formed by soldering bismuth to antimony is heated, an electric current will flow through the joint from the bismuth to the antimony. This depends on the unequal powers of the two metals as conductors of heat. Parallel
fact in
thermo-
electricity.

If a current *from an external source* is sent through the joint from the bismuth to the antimony (consequently in the same direction as the current that would be produced by *heating* the joint), the joint will be *cooled*. If the current is sent through the joint in the opposite direction, the joint will be heated.[2]

The only possible explanation of the cooling of the joint is, that the passage of the electric current through it determines the conversion of part of its heat into electricity; and this is analogous to the commencement of muscular action determining the conversion of part of the heat of the muscle into muscular motor energy.

Both of these cases are exceptional. They are, I believe, the only known instances of the conversion of heat into any other form of energy being caused by the passage of a current of that other form of energy. These
cases are
excep-
tional.

[1] Solger, and Meyerstein and Thiry, quoted in the Medico-Chirurgical Review, January 1864.

[2] Tyndall, in the Philosophical Magazine, December 1852.

CHAPTER X.

ORGANIZATION.

Three kinds of formative principles; THERE are in nature three kinds of formative principles, each of which produces its own characteristic forms, totally unlike those of the others.

the first forms spherical aggregations. All forces which are simply attractive produce spherical forms. Gravitation and capillarity are forces of this class: a planet, which owes its spherical form to gravitation, and a rain-drop, which owes it to capillarity, are both instances of this kind of formative principle. In such aggregations there is not necessarily any structure: a rain-drop has no structure: and when there is any, it consists merely in stratification; that is to say, in the deposition of layers of substance round the centre of the sphere. An agate **Agate nodules,** nodule is a good instance of this: every one is familiar with the beautiful markings, approximating in form to concentric circles, which are presented when the spherical nodules of agate are cut through and polished, so as to show their structure, and which are due to the nodule consisting of concentric layers stratified round its centre. Whatever may be the kind of force to which the formation of these nodules is due, whether it is only capillarity acting under special circumstances, or some quite peculiar species of force, it is evidently a simply attractive force like gravitation or capillarity, and not a polar force like that of a magnet.

It is evident also that the structure of the agate nodule **having structure depending on form.** depends on its form, and not the converse. The relation of structure to form, indeed, consists in this, that the solid sphere is composed of a number of concentric hollow

spheres. It may be worth mentioning that hailstones have
been found with a structure like this, or, to use a more Hailstones.
familiar though less really apposite comparison, composed
of coats like those of an onion. This structure is probably
due to their being attracted and repelled back and forwards
between two oppositely electrified clouds, like the pith
balls used in electrical experiments.

The second kind of formative principle is that to which Second
the form and structure of crystals are due. This is different $\substack{\text{kind, pro-} \\ \text{ducing}}$
from the former, and much more complex. It is evident crystals,
that the force which brings the particles of a salt or other
crystallizing substance together from the water in which it
is in solution, must be an attractive force. But it is not
simply attractive. A simply attractive force, when acting
alone, can, as already remarked, produce none but spherical
forms. It is, in the largest sense of the word, a *polar*
force; that is to say, a force that acts differently in different
directions: for crystals are never spherical, but are, when
normally formed, always bounded by plane surfaces.
There is also this difference, that in spherical forms the having
structure, when there is any, depends on the form; but in $\substack{\text{forms de-} \\ \text{pending on}}$
crystalline forms the form depends on the structure. This, structure.
as to crystals, may need explanation. In crystallization
the essential point, as stated in the chapter on that subject,
is not the form, which is variable for the species, but
the relation between the axes, which is constant, and
which constitutes the structure; and any form is possible
in a species if the angles at which the planes are
inclined on each other are such as to be consistent with
the relations between the axes of that species. The
dependence of form on structure may be thus experi-
mentally illustrated. A mineralogist finds a lump of some
mineral substance that presents no definite form; but from
its lustre, or some other characteristic, he suspects that it
is crystalline; and by a few properly-directed blows of
his hammer he breaks it in the direction of its cleavage,
splitting it into large fragments bounded by faces which
are parallel to the cleavage planes, and make angles on
each other that are consistent with the relation between

the axes of the species. A form thus obtained, depending
on cleavage, is as truly a natural one as if it were obtained
simply by picking it up; and it manifestly depends on
structure, of which cleavage is one of the most important
expressions.

Third
kind,
producing
organisms.
The third kind of formative principle is that of vital
organization, to which the forms and structures of organisms
are due. The organic formative principles probably tran-
scend in complexity those which form crystals, almost
infinitely more than those which form crystals transcend
those which form spheres. Concerning the formation of
spheres there is no mystery whatever. Gravitation, and
every other primary force and ultimate property, are no
doubt inexplicable; but, if we take the force as a datum,
it is self-evident that a force which is simply attractive
must tend to produce aggregations of spherical form.
Concerning the formative principles of crystallization we
know very little as yet; but it does not appear beyond the
powers of man's intellect to find mathematical expressions
for the complex polarities that determine the characteristic
structure and form of every crystalline species, and even
Organiza-
tion inex-
plicable.
to discover their physical laws.[1] But it never can be
possible to give any mathematical statement, or any
physical explanation of those mysterious formative prin-
ciples in virtue of which the structureless and homo-
geneous germ of an organism acquires definite structure,
and separates into distinct organs.

It needs no proof that in the case of spheres and
crystals the forms and the structures are the effect,
and not the cause, of the formative principles. Attrac-
tion, whether gravitative or capillary, produces the spherical
form: the spherical form does not produce attraction.
And crystalline polarities produce crystalline structure
and form: crystalline structure and form do not produce
crystalline polarities.

[1] See the chapter in Dana's Mineralogy on "Theoretical Crystallogeny."
Also an article by the same author in the Philosophical Magazine,
September 1867, on the connexion between chemical constitution and
crystalline form.

The same is not quite so evident of organic forms, but it is equally true of them also. Organic form and structure are the result of the organic formative principle; or, in briefer words, life is the cause of organization: organization is not the cause of life. Organization is not essential to life: it is not the differentia of living beings. The differentia of living beings consists, I believe, in those peculiar relations to matter and energy which have been explained in the last chapter: organization is only one of the most general and most important results of life.

Life is the cause of organization.

The proof of this is, that while, as every one will admit, there can be no organization except where there has been life, there may be, and is, life where there is no organization. It is an observed fact, independent of any inference or any theory, that life exists prior to organization. The germs of organisms are not miniatures of the perfect form, nor are the perfect forms produced from the germs by any process that can be properly described as unfolding: on the contrary, the germs are without structure and without definite form, and have no character whatever, whether chemical or microscopic, by which the germ of one organism can be known from that of another, however unlike the species may be.[1] This fact, that all organisms are developed out of perfectly simple germs, is, from a purely scientific point of view, probably the most important of all the discoveries of modern physiology. But though without structure, the germ assimilates matter and grows, thus showing that it possesses the characteristically vital properties with respect to matter, and probably with respect to energy also.[2] In all but the very lowest classes of organisms, the germ, as it grows, acquires structure and organization. But it is a most significant fact, that some of the lowest animals (of which the amoeba is probably the best-known type) never acquire any structure whatever, or any constant form: they continue to be mere minute gelatinous masses, which however exercise those

Organic germs are without structure,

as are some mature organisms.

[1] Carpenter's Comparative Physiology, p. 25.

[2] See the preceding chapter. It is to be regretted that we have no single word for *living being* except *organism*, a word which suggests the untrue notion that organization is the essential point in life.

I

nutritive and motor functions that show them to have the characteristically vital relation to matter and energy. And

Germinal matter has no structure.

the "germinal matter" of organisms, previous to its transformation into their "formed material," is without structure, though it has in the highest degree what I regard as the characteristically vital properties.

Crystallization and organization.

It needs no proof that the unformed but formative material of a crystallizable substance (as, for instance, a salt while in solution) has a constant tendency to assume the form and structure of the crystalline species, and does assume it when circumstances favour. The same is true of the unformed but formative material, or "germinal matter," of organisms; the germinal matter of every organic species constantly tends to assume the form and structure of the species to which it belongs. Hence is the power of a germ, when placed under favouring circumstances, to transform itself into the perfect form of its species. Hence. (what is essentially the same property) the power, among many plants and among the lowest animals, of a cut-off part to transform itself into a perfect individual. And, what is only a lower degree of the same, the power of repairing injuries, which all organisms possess in a sensible degree, and which has been observed also in crystals.[1]

Reaction of formed on unformed material.

In organisms also, as in crystals, the formed material reacts on the properties of the unformed but formative material. The strongest instance of this is the sympathetic reproduction of injuries, which, as we have seen, occurs in crystals[1] as well as in organisms, and is due to the formed material, which has suffered the original injury, modifying the further action of the formative material.[2]

But what is organization? and how does organic structure essentially differ from crystalline structure?

[1] P. 75.

[2] Dr. Beale speaks of different kinds of germinal matter. But notwithstanding my high respect for his scientific attainments and scientific services, I submit it is much more likely that there should be only one kind of germinal matter in each organic species, and that this ministers to the growth of whatever tissue it occurs in. This view is supported by the fact, that the smallest portion from any part of an hydra, or other such low organism, will reproduce the entire form belonging to the species.

The most obvious answer to this question perhaps would be, that the structure of a crystal is alike throughout and in every part, but that of an organism is different in different parts; the leaves and the wood of a tree, for instance, are of different structure, and so are the bones, the muscles, and the nerves of an animal. But we have seen that though crystals are generally perfectly alike in structure throughout, there are some perfectly regular crystals, which, when they are examined by the infallible test of polarised light, show a difference of structure between their different parts.

The essential difference between organization and any kind of inorganic structure is quite different from this: organization is the adaptation of structure to function. *Organiza-* This principle, of adaptation of structure to function, and *tion de-* of one structure and one function of an organism to *fined.* another, is characteristic of the organic creation, and is utterly unlike anything that we meet with in the inorganic world.

There are three principles of logical relation, that run *Three re-* like guiding threads through physical science. These are— *lations in* *science :*
1. The relation of cause and effect ; *Cause,*
2. The relation of resemblance and difference ; and *Resem-*
blance,
3. The relation of means and purpose. *Purpose.*

For the sake of brevity let us call these cause, resemblance, and purpose. Of course I do not offer this as a complete enumeration of all possible relations : I well know that it is nothing of the kind. I only say that, as a matter of fact, these are the most important relations that we meet with in the physical sciences.

The relation of cause is almost the only one that the *Sciences* dynamical sciences have to do with: under which title I *of cause.* include not only general dynamics, but the sciences of sound, radiance, heat, electricity, and magnetism ; which are all now recognised as special cases of dynamical theory. And the same is, in a great degree, true of those more *Chemistry.* elementary branches of chemistry that have to do with the general properties of matter, and with the relations of composition and decomposition to heat and to electricity.

The general problem of this whole group of sciences is to infer causes from effects and effects from causes.

But in the higher or more complex chemistry, especially in the chemistry of organic compounds, the known and possible combinations are so many, and the variety of interactions is so great, that in the present state of science it is impossible to do for chemistry what we have been doing since Newton's time, and are still doing, for the dynamical sciences; namely, to refer the multitude of phenomena to a few causes, of which the phenomena are effects.

Every science, however, must have some principle, or principles, of logical relation; were it without any, it would not be a science at all, but only a mass of unconnected facts. In chemistry, this very multiplicity, variety, and complexity of the facts, which places any knowledge of their causes at present beyond our reach, supplies us Sciences of resemblance, or with a new principle of scientific relation: that of resemblance. Compounds are not formed without relation to each other, or as it were at random; they are formed in series, and in series of series; and this relation is most decided in the higher or more complex chemistry. classificatory sciences. Chemistry, in its higher branches, has thus become a classificatory science; and the most important result which has been yet achieved in the higher chemistry consists in the establishment of the theory of types and substitutions, by which a rational classification of the vast multiplicity of compounds has been made possible.

Crystallography. Crystallography also is a science in which causes are as yet almost totally unknown. We know little or nothing of the causes that determine crystalline formation; we can only describe and classify crystals by their chemical, geometrical, and optical properties. Crystallography, or the science of crystallization, is thus a classificatory science. We have seen that chemical compounds are formed in series, and in series of series. Crystalline species exist in groups, and in groups of groups; or, to use technical language, in genera and classes.[1]

[1] The difference between a series and a group is, that the names of the members of a series can be properly enumerated in only one order, those

A very large part of biology, or the science of life,[1] Biology. consists, like crystallography, in the description and classification of the forms of various species. Organic species, like crystalline species, exist in groups, and in groups of groups. The description of the forms, both in crystallography and in biology, constitutes morphology; and the Morphodetermination of the fundamental relations (which are not logy. always the obvious ones) between the forms is the problem of classification. Biology, like crystallography, is thus a classificatory science.

It appears to be the opinion of many, that questions of classification are merely questions of names, and consequently of no true scientific importance. They think that the expression *true* classification is without meaning, and that a classification will serve every purpose that it possibly can serve, if it is only generally agreed on, so as to prevent confusion in the use of names; and intelligible, so as to make reference easy. According to this view, the question whether a whale is a fish or a mammal, and whether a barnacle is a mollusc or a crustacean, are questions of words only, not of realities; though some words or names may be more conveniently applicable than others.

The fallacy, or rather the inadequacy, of this notion is Importnot easy to prove in any demonstrative form: and it must ance of suffice here to assert, that every one who has experience of tion. the study of any science whatever to which the classificatory method is applicable, becomes convinced, if he was not so at the commencement, that true classification is one of the greatest possible helps to knowledge, and inaccurate classification one of the greatest possible hindrances.

True classification may be defined as classification ac- Its basis cording to the resemblances and differences of the *funda-* in funda-

of a group may be enumerated in various orders. The different oxides of a metal, for instance, which are formed by the successive addition of equivalents of oxygen, form a series.

[1] I intend to use this word throughout. We need a word that shall apply to the life of animals and of vegetables alike, and that shall include both morphology, or the science of organic forms, and physiology, or the science of vital functions. I do not know who first coined the word, but it is used by Comte in his Positive Philosophy.

a group depends, are determined by the "law of development" in a way that is altogether peculiar to biological science, as I shall have to explain farther on.

But the description, comparison, and classification of organic species—that is to say, organic morphology—constitute only one-half of the science of biology, and that its least characteristic half. Crystals, like organisms, have their morphology and their classification; but in crystals there is nothing but structure to consider: there is no adaptation of structure to function, because there is no function. Function (in the organic, not the mathematical sense) is impossible and inconceivable in such bodies as crystals, which can continue to exist only under the condition of perfect molecular immobility, and cease to be crystals if this is disturbed. In organisms, on the contrary, every structure is adapted to its function, and structure depends on function. Consequently, the second, and most characteristic part of biology, consists in physiology, which is defined as the science of organic functions, and of the relations of structures to their functions. *Morphology.* *Physiology.*

I call physiology the most characteristic part of biology, because, by the definition, physiology alone takes cognizance of that relation of structure to function, or, what comes to the same thing, of means to purpose, which is peculiar to the organic creation. We have seen that the relation of cause and effect is the characteristic relation in the dynamical sciences, and that of resemblance and difference is the characteristic one in the classificatory sciences. Biology is a classificatory science; but the relation of means and purpose is also a characteristic one in biology, and is found there alone.

From this point of view, we may say that morphology is the classificatory side of biological science, and physiology its functional side.

I may be told, that when I say that the relation of structure to function is the same thing with the relation of means to purpose, I am assuming as true an hypothesis which has not been, and cannot be, verified.

I reply, that the relation of special structure to special

Purpose in function, as for instance the relation of the structure of
creation
peculiar to the eye to the function of vision, is something which has
organiza- no analogy whatever in the inorganic creation, though it
tion:
has analo- has analogies in machinery and other apparatus of human
gies in invention. The analogy of the eye to the camera obscura
man's
work. is a case in point; in fact, the eye is a camera. And in
speaking of such organic adaptations, we naturally and
almost inevitably fall into the habit of regarding special
function as a proof of purpose; and of speaking of the
function of an organ and of its purpose, as if the words
were synonymous: and this habit is not found to be mis-
leading; on the contrary, it is a rule in physiological
research (though subject to a few very remarkable excep-
Organic tions), that every organ, and every structural arrangement,
structure
implies must have its own special purpose. These are facts, very
function. much generalized no doubt, but still facts of observation,
concerning which there is no room for doubt or controversy.
But when it is denied that there is any discernible purpose
in the organic creation, the meaning appears to be, that
the relation of special structure to special function, or
what I have called the relation of means to purpose, is in
reality only a particular case of the relation of cause and
Is this effect. It would be impossible for any man of the slightest
relation
a case of intelligence, simply to deny the existence of the most
that of wonderful special adaptations in the organic creation.
cause and
effect? But though not a plausible doctrine it is an arguable one,
and has been maintained with great knowledge and great
ability by Darwin in his "Origin of Species," and by
Spencer in his "Principles of Biology," that the laws of
cause and effect are adequate to account for all these; that
the adaptation of the eye to light, for instance, has been
produced by the direct and indirect action of light on
countless generations of living beings: and so of all other
organic adaptations.

I believe   From this theory I utterly dissent, and in a future
not. chapter I shall give reasons which I regard as conclusive
against it. I believe that the relation of means and pur-
pose in organization is as much a primary law of nature,
and as incapable of being resolved into any other more

general principle, as the relation of cause and effect. I
will here only remark, as a presumption against the theory
in question, that as we ascend in the scale of nature to
higher and higher vital functions, and higher and higher
organic forms, we find the relation of cause and effect
becoming less traceable by our faculties (though no doubt
it exists all through nature); while at the same time the
relation of means and purpose becomes at once more Purpose is
traceable and more definite. Nowhere in the universe as able, and
known to us, is the relation of means to purpose more cause less
clearly traceable and more perfectly definite, than in the ascend in
organs of special sense in the higher animals, especially in nature.
the eye and the ear; and nowhere is it more difficult (I
would say, utterly impossible) to assign any physical cause
for the facts, as when we inquire by what cause, or by
what agency, such wonderful organs have been formed.
And as we ascend in nature, not only do the separate
functions become more traceable, but their mutual relations
become more definite. The trunk, the leaves, and the
flowers of a tree, for instance, have each their function,
but it would be unmeaning to ask whether the tree exists
for the leaves or the leaves for the tree. But in all the
higher animals, the parts manifestly exist for the whole,
not the whole for the parts.

 This truth, that purpose is most clearly discoverable
where cause is least so, has not received the attention it
deserves.

 But all the purposes that biological science reveals to us Purposes
are only relative purposes—that is to say, purposes which zation are
are means to other purposes : we learn nothing of any ab- only rela-
solute, ultimate purpose, which is an end in itself, and not tive.
a means to some other end. Thus, the purpose of the eye
is to see, of the ear to hear, of the lungs to aërate the
blood, of the heart to circulate it, &c.: every organ
ministers to the life of the whole organism. As Kant
acutely remarked, in an organism all the parts are mutually
means and ends : meaning, that all the parts mutually
minister to each other. But if we ask what *absolute* ·end
is served by this wondrous play of means and *relative*

the axes of the species. A form thus obtained, depending on cleavage, is as truly a natural one as if it were obtained simply by picking it up; and it manifestly depends on structure, of which cleavage is one of the most important expressions.

Third kind, producing organisms.

The third kind of formative principle is that of vital organization, to which the forms and structures of organisms are due. The organic formative principles probably transcend in complexity those which form crystals, almost infinitely more than those which form crystals transcend those which form spheres. Concerning the formation of spheres there is no mystery whatever. Gravitation, and every other primary force and ultimate property, are no doubt inexplicable; but, if we take the force as a datum, it is self-evident that a force which is simply attractive must tend to produce aggregations of spherical form. Concerning the formative principles of crystallization we know very little as yet; but it does not appear beyond the powers of man's intellect to find mathematical expressions for the complex polarities that determine the characteristic structure and form of every crystalline species, and even

Organization inexplicable.

to discover their physical laws.[1] But it never can be possible to give any mathematical statement, or any physical explanation of those mysterious formative principles in virtue of which the structureless and homogeneous germ of an organism acquires definite structure, and separates into distinct organs.

It needs no proof that in the case of spheres and crystals the forms and the structures are the effect, and not the cause, of the formative principles. Attraction, whether gravitative or capillary, produces the spherical form: the spherical form does not produce attraction. And crystalline polarities produce crystalline structure and form: crystalline structure and form do not produce crystalline polarities.

[1] See the chapter in Dana's Mineralogy on "Theoretical Crystallogeny." Also an article by the same author in the Philosophical Magazine, September 1867, on the connexion between chemical constitution and crystalline form.

The same is not quite so evident of organic forms, but it is equally true of them also. Organic form and structure are the result of the organic formative principle; or, in briefer words, life is the cause of organization: organization is not the cause of life. Organization is not essential to life: it is not the differentia of living beings. The differentia of living beings consists, I believe, in those peculiar relations to matter and energy which have been explained in the last chapter: organization is only one of the most general and most important results of life. *Life is the cause of organization.*

The proof of this is, that while, as every one will admit, there can be no organization except where there has been life, there may be, and is, life where there is no organization. It is an observed fact, independent of any inference or any theory, that life exists prior to organization. The germs of organisms are not miniatures of the perfect form, nor are the perfect forms produced from the germs by any process that can be properly described as unfolding: on the contrary, the germs are without structure and without definite form, and have no character whatever, whether chemical or microscopic, by which the germ of one organism can be known from that of another, however unlike the species may be.[1] This fact, that all organisms are developed out of perfectly simple germs, is, from a purely scientific point of view, probably the most important of all the discoveries of modern physiology. But though without structure, the germ assimilates matter and grows, thus showing that it possesses the characteristically vital properties with respect to matter, and probably with respect to energy also.[2] In all but the very lowest classes of organisms, the germ, as it grows, acquires structure and organization. But it is a most significant fact, that some of the lowest animals (of which the amœba is probably the best-known type) never acquire any structure whatever, or any constant form: they continue to be mere minute gelatinous masses, which however exercise those *Organic germs are without structure,* *as are some mature organisms.*

[1] Carpenter's Comparative Physiology, p. 25.
[2] See the preceding chapter. It is to be regretted that we have no single word for *living being* except *organism*, a word which suggests the untrue notion that organization is the essential point in life.

I

nutritive and motor functions that show them to have the characteristically vital relation to matter and energy. And the "germinal matter" of organisms, previous to its transformation into their "formed material," is without structure, though it has in the highest degree what I regard as the characteristically vital properties.

Germinal matter has no structure.

It needs no proof that the unformed but formative material of a crystallizable substance (as, for instance, a salt while in solution) has a constant tendency to assume the form and structure of the crystalline species, and does assume it when circumstances favour. The same is true of the unformed but formative material, or "germinal matter," of organisms; the germinal matter of every organic species constantly tends to assume the form and structure of the species to which it belongs. Hence is the power of a germ, when placed under favouring circumstances, to transform itself into the perfect form of its species. Hence (what is essentially the same property) the power, among many plants and among the lowest animals, of a cut-off part to transform itself into a perfect individual. And, what is only a lower degree of the same, the power of repairing injuries, which all organisms possess in a sensible degree, and which has been observed also in crystals.[1]

Crystallization and organization.

In organisms also, as in crystals, the formed material reacts on the properties of the unformed but formative material. The strongest instance of this is the sympathetic reproduction of injuries, which, as we have seen, occurs in crystals[1] as well as in organisms, and is due to the formed material, which has suffered the original injury, modifying the further action of the formative material.[2]

Reaction of formed on unformed material.

But what is organization? and how does organic structure essentially differ from crystalline structure?

[1] P. 75.

[2] Dr. Beale speaks of different kinds of germinal matter. But notwithstanding my high respect for his scientific attainments and scientific services, I submit it is much more likely that there should be only one kind of germinal matter in each organic species, and that this ministers to the growth of whatever tissue it occurs in. This view is supported by the fact, that the smallest portion from any part of an hydra, or other such low organism, will reproduce the entire form belonging to the species.

The most obvious answer to this question perhaps would be, that the structure of a crystal is alike throughout and in every part, but that of an organism is different in different parts; the leaves and the wood of a tree, for instance, are of different structure, and so are the bones, the muscles, and the nerves of an animal. But we have seen that though crystals are generally perfectly alike in structure throughout, there are some perfectly regular crystals, which, when they are examined by the infallible test of polarised light, show a difference of structure between their different parts.

The essential difference between organization and any kind of inorganic structure is quite different from this: organization is the adaptation of structure to function. Organiza-
This principle, of adaptation of structure to function, and tion de-
of one structure and one function of an organism to fined.
another, is characteristic of the organic creation, and is utterly unlike anything that we meet with in the inorganic world.

There are three principles of logical relation, that run Three re-
like guiding threads through physical science. These are— lations in
science :

1. The relation of cause and effect ;   Cause,

2. The relation of resemblance and difference ; and   Resem-
blance,
3. The relation of means and purpose.   Purpose.

For the sake of brevity let us call these cause, resemblance, and purpose. Of course I do not offer this as a complete enumeration of all possible relations : I well know that it is nothing of the kind. I only say that, as a matter of fact, these are the most important relations that we meet with in the physical sciences.

The relation of cause is almost the only one that the Sciences
dynamical sciences have to do with: under which title I of cause.
include not only general dynamics, but the sciences of sound, radiance, heat, electricity, and magnetism; which are all now recognised as special cases of dynamical theory. And the same is, in a great degree, true of those more Chemistry.
elementary branches of chemistry that have to do with the general properties of matter, and with the relations of composition and decomposition to heat and to electricity.

germinal matter into the formed material of the tissues. When it goes on abnormally in the reproduction of a lost part, it is effected in what is essentially the same way; namely, by the transformation of the germinal matter, or unformed material, which is found in small quantities throughout every living part of every organism, into the formed material of the part that is being reproduced. The food which is assimilated by an organism, whether by a vegetable or by an animal, is *vitalized* before it is *organized*; in other words, it is transformed into formless and structureless germinal matter first, and into the formed material of the tissues afterwards. This is equally true of the development of the original germ into the form of its species; of the growth of the individual to maturity, after it has assumed its form; of the renewal of tissue which is constantly going on to supply waste, even after growth has ceased; and of abnormal acts of development in the healing of wounds and the reproduction of lost parts. In all cases the assimilated food is transformed into germinal matter, and the germinal matter into formed material. It is to be observed, also, that in acquiring structure the germinal matter loses its plastic properties. The power of growth, development, and transformation generally, which is characteristic of organisms, appears to reside, not in the formed material, but in the germinal matter; and the more completely has the formed material assumed a character unlike that of germinal matter, the more completely has it lost the power of undergoing spontaneous transformation and development. This would be difficult to prove by any observations or experiments on the higher organisms, but it is at least consistent with what we know of them; and the lower ones afford experimental illustration of it. The Rhizopods are the simplest of all animals, and scarcely present a trace of organization; but many of them show, in its simplest form, the distinction between germinal matter and formed material. The *gromia*, for instance, consists of nothing but a minute mass of gelatinous matter, enclosed in a membranous sac, which is open at one end.[1] If the

Germinal matter is without structure.

Formed material cannot be further transformed.

Gromia.

---

[1] Carpenter on the Foraminifera, published by the Ray Society, p. 63.

gelatinous matter is emptied out of the sac, it will form a
new sac for itself; but the sac will not form any germinal
matter, nor will it manifest any vital properties.   Here is
the first and simplest distinction of germinal matter and
formed material; and we see that the germinal matter will
produce formed material, but the formed material will not
produce germinal matter.

Formed material, however, is also produced in another
way; not by separation from the germinal matter, as I
have just described in *gromia*, but by gradual transforma-
tion of the germinal matter itself into formed material.   It
is in this manner that a fibrous structure, a kind of rudi-
mentary muscular tissue, has been observed to originate in
the larvæ (or, to speak more correctly, the free swimming
embryos) of the Echinoderms;[1] and I think it likely, though   Larvæ of
I have not met with the remark, and do not speak with any   Echino-
confidence, that this mode of development is characteristic   derms.
of muscular and other characteristically animal tissues;
while development by means of the separation of the
formed material from the germinal matter, as in the
gromia, is characteristic of vegetables, and of those animal
tissues in which vegetative or nutritive functions are
carried on.

When the formed material is separated from the germinal
matter, the separation takes place on the outside of the
mass of germinal matter; and this gives origin to cells, of   Cells.
which the inside consists of the soft, half-liquid germinal
matter, and the outside of harder formed material.   The
gromia, described above, is an animal consisting of a single
cell; and there are whole tribes of vegetables that consist of
the same, especially the Diatomaceæ and the Desmideæ,
which are classed as very simple forms of Algæ.   A great
part of the tissues of the higher animals and vegetables   Cellular
consists of such cells, variously modified.   So common,   tissue.
indeed, is this simple formation, that the cell used to be
regarded as the primary element of all organized tissue
whatever; but the observations on the larvæ of the

---

[1] Professor Wyville Thomson on the Embryology of the Echinodermata,
Natural History Review, October 1864.

Echinoderms mentioned above, and many others, have shown that such is not the case.

In speaking of the *gromia*, we have seen that germinal matter will produce formed material, but formed material will not produce germinal matter. In the case of the higher organisms, it is of course impossible to give the same experimental proof; but all evidence and all analogy leads to the conclusion that the same relations hold throughout the whole organic creation. Germinal matter, similar in appearance and general properties to the *sarcode*, or gelatinous living substance of such organisms as *amœba, gromia*, and *hydra*, is found in the tissues of all living organisms, and is most abundant in those which are growing most rapidly. It is also found in the blood: the " white blood-corpuscles " consist of this germinal matter, and are without structure, but show their vitality by spontaneous movements like those of an *amœba*.

Sarcode.

White blood-cor-puscles.

But it may be objected to this theory, that if the formative powers of an organism reside in the as yet unorganized germinal matter dispersed through it, a cut-off part of one of the higher organisms ought to manifest independent vitality, like a cut-off part of a *hydra*, which, in virtue of its germinal power, will transform itself into a complete *hydra*.

Why the higher organisms do not live when cut in pieces.

I reply, that the difference in this respect between the lowly *hydra* and the highest organisms, such as an elephant or a man, consists in this: that any fragment of a *hydra's* body can live wherever it has water and food; but the germinal matter of the higher organisms has no such power—it can only live within the body of an individual of the species to which it belongs, and when this is greatly injured its germinal matter dies with it.

The same difference explains the difference between the mode of propagation among the lowest organisms and the highest ones. It is probable, though not yet certain, that true sexual generation is universal among all organic species. But the lowest organisms, such as the Rhizopods among animals and the Diotomaceæ among plants, often propagate by spontaneous division: the organism separates

Propaga-tion by sponta-neous division,

into two parts, each of which contains a portion of germinal matter, and continues to live and to grow.   The *hydra* is a little more highly organized than these, and, so far as is known, does not spontaneously divide, though, as already mentioned, separated parts will live.   Its usual mode of propagation is by means of buds, which may be formed on any part of its external surface, and rapidly develop into perfect *hydræ*, when they detach themselves and creep away.   This mode of propagation is, as every one knows, very common among plants, except that the buds of plants seldom detach themselves.

and by budding.

In these modes of propágation the reproductive power belongs to every part of the organism alike; but in the higher animals the reproductive power is confined to the organs of generation, the function of which is to prepare and throw off masses of germinal matter in such a form as shall be best suited for independent life, and, further, to provide the germ with protection and nourishment, either in the egg or in the womb of the mother, until it has attained to some degree of maturity.[1]

Separate generative organs in the higher classes.

We have seen that all living beings whatever have been developed out of perfectly simple germs, and that the germs—the germinal matter—of all species and all classes are to appearance exactly alike.   This is no mere inference, but an observed fact.   The further question is now suggested, whether this course of development, which is repeated in the biography of every individual organism, has taken place in the history of every species.   Have species and classes of organisms, like individuals, been

Origin of species: is it also by development from simple germs,

[1] It will be observed that I have adopted Dr. Beale's views on the subject of "germinal matter," as set forth in his edition of Todd and Bowman's Physiology.   I regret, however, that Dr. Beale has stated a theory, which I believe to be true and most valuable, in language that can scarcely fail to excite a prejudice against it.   He speaks of life as being confined to the germinal matter; by life, evidently meaning the formative principle.   In the sense in which he uses the word, I have shown that I think he has given reasonably good proof that it is so.   But it is an unwarrantable liberty with language, to use the word *life* in a sense which would exclude the contractility of muscle, and the sensibility of nerve, from the denomination of vital functions.

K

produced by slow and gradual development from perfectly simple germs? or is the presumption in favour of the old belief, that every species has been separately created, and created as we find it? According to the "theory of development," as it is usually called, all the organic species, vegetable and animal, which are living or ever have lived, are descended from one or a few ancestors, which had life, but not organization; and all the wondrous organization and other vital properties which the various species of organisms possess, over and above those powers of transforming matter and energy which, as we have seen, constitute the differentia of life, have been acquired by gradual modification through descent for countless generations. I have purposely stated the development theory in its most extreme form. Various intermediate theories — compromises as they may be called—are no doubt possible between the development theory and the opposite theory of separate creations. We may suppose separate ancestors, for instance, for the animal and vegetable kingdoms, or separate ancestors for each of the great primary divisions of the two kingdoms, or for groups of any less magnitude. But these compromises are seldom made, and are scarcely worth any attention. It appears to be generally felt that the same arguments which are relied on to show the strong probability of the common origin of distinct though nearly allied species—as, for instance, the horse and the ass—are equally valid for showing the probability of a common origin for all organic species whatever.

through descent with modification?

I am a believer in the development theory to its fullest extent; and I intend in the succeeding chapters to state my reasons for thinking that there is an accumulation of probabilities in its favour almost amounting to proof. I believe that the arguments in its favour will appear stronger the more the subject is understood; and that the objections to it, on the contrary, are more apparent than real.

I believe so.

I must apologize beforehand for the deviations from strict logical method which the reader may expect. In writing on any subject to which demonstration is applicable, nothing ought to be taken as proved until it is

Deviations from strict logical method.

proved. But these are inquiries in which demonstration
is out of the question. The proof is, perhaps, equivalent
to demonstration, but it is not of the same kind: it con-
sists of an accumulation of probabilities; it rests on the
consistency of the argument with itself, and with a multi-
tude of facts of various sorts; and it involves laws with
which at first sight it may appear to have nothing to do.
In elaborately stating an argument of this kind, I fear it
will be scarcely possible for me to avoid appearing some-
times to take that for granted which I mean to prove.

It is to be observed that the origin of species and the
origin of life are totally distinct questions. As stated
above, I believe that species have originated by descent,
with modification, from one originally vitalized but un-
organized germ, like the germs of existing organisms. But,
as stated in the chapter on the Chemistry of Life, I believe
that the original germ must have been vitalized by the
same Creative Power that gave their origin and their
properties to matter and energy.

On these two points I agree with the views stated by
Darwin in his work on the " Origin of Species." But to
Darwin's special and characteristic theory I am altogether
opposed. I do not believe that " natural selection among
spontaneous variations," or any other physical process or
agency whatever, will account for the most remarkable
facts of organization.

Origin of species, and origin of life, distinct questions.

CHAPTER XII.

THE DIRECTION OF DEVELOPMENT.

Highest development is greatest complexity, A S we have already seen, all development is from the simple to the complex : all organisms have their origin in perfectly simple germs, and their development goes on to constantly increasing complexity. Consequently, the highest development is the greatest complexity; the highest organisms are those of most complex structure.

and greatest distinctness of dissimilar parts. But when we say that the most complex organisms are the most highly organized, we do not mean that high organization consists in mere multitude of parts. The multitude of leaves on a tree is no mark of high organization. What constitutes high organization is not *multitude* of *similar* parts, but, what is quite different, *distinctness* of *dissimilar* parts. In man, or any other of the highest organisms, there are no two parts exactly alike, except those which correspond with each other on the opposite sides of the body.

In the chapter on the Dynamics of Life it has been stated that all organisms are constantly acquiring matter by assimilation, and parting with it by waste; and that they are also constantly storing energy, and parting with it again—transforming it, usually, into either motion or heat: and, moreover, all organisms propagate their kind, whether by spontaneous division into parts, or in some other less simple manner. All organisms whatever, consequently, even those which are so simple as to be without structure, have a considerable complication of functions : and progressive organic development consists in the fitting of

separate parts of the organisms for the discharge of the separate functions; one set of organs for the nutritive or assimilative function, another for the excretory, another for the motor, another for the reproductive, and so on. To use an expressive metaphor—and, indeed, more than a metaphor, a real analogy—vital organization consists in framing the various parts of the organism for the *physio-* Physiologi- *logical division of labour;* and those are the most highly cal division organized beings in which the distinctness of tissues and of labour. organs, and consequently the physiological division of labour between them, are carried the farthest.

In the lowest organisms, as we have seen, every part discharges all functions : there is no physiological division of labour at all. And even in the highest it is not com- Never plete : some of the organs have to a great extent the power quite com- of discharging the functions of others. In man, for in- plete. stance, the skin and the kidneys are to a great extent able each to do the work of the other in separating water and soluble substances from the blood; and in some cases of disease one excretory organ assumes the whole work of another. This power, which is so utterly unlike anything in human machinery, is no doubt in some way due to the common origin of all organs and all tissues in the body in the original homogeneous and structureless germ.[1]

But, as we have seen, the highest organization is that in which the various parts are each most thoroughly fitted for its own peculiar function, and where, consequently, each part has least power to discharge any function, or do any work, other than its own. It follows from this that the highest organisms are those in which the combination Combined of the action of the various parts is most perfect; and in action of them, also, the combination of the action of the various most per- parts is most necessary. In other words : in the highest fect in the organization the various parts minister to each other most organisms. perfectly, and are least able to do without each other. In such a low organism as a *hydra*, for instance, the mutual dependence of parts is so slight, that if the animal be cut in pieces, each part will become a perfect individual; and

[1] Carpenter's Human Physiology, p. 374.

the same power belongs to many worms, which are much more highly organized than the *hydra;* but in no vertebrate animal does this power extend further than to the reproduction of lost parts ; and in man, and other warmblooded animals, it usually extends, in mature life at least, only to the healing of wounds. Thus, the higher the organism, the less are the parts able to do without each other.

I have used an analogy drawn from the science of man's social relations to illustrate the unlikeness of structure and separation of function between the various parts of the organism ; and I may use another analogy from the same science to illustrate the mutual dependence of parts, and the combination of their actions, which is the result of that unlikeness. The separation of their functions is called the *physiological division of labour :* their mutual

Physiological centralization, or combination. dependence, and the combination of their action, may be called *physiological centralization.* In the organism, as in human society, division of labour is necessary to combination ; and combination (or centralization, as it is called in politics [1]) is necessary to division of labour. It appears to be a general law, grounded in the nature of things, that

Special perfection in an organ is incompatible with general adaptability. high perfection for any special purpose is in a great degree incompatible with adaptation, or adaptability, to a variety of purposes. This is true alike of tools, of members of the living organism, and of men. It is impossible, for instance, for a hammer and a plane to do each other's work. It is inconceivable that the hand and the eye should exchange functions. And it is a familiar remark, that a man who has attained to perfection in some mechanical—and perhaps I may add, in some intellectual—employment is thereby in a great degree incapacitated from any employment that needs nothing but the power of doing a variety of work

[1] I ought perhaps to remark here that any argument in favour of political centralization which may be based on this analogy is not only too *far-fetched* (to use a most appropriate colloquial metaphor) to be of much practical value, but it is utterly vitiated by this difference, which is practically all-important, that in the living organism the parts exist for the whole, but in society the whole exists for the parts—society exists for its members.

moderately well.   In the living organism, and in human Efficiency
society alike, the purpose of division of labour is to increase of each and all
the efficiency of every member ; the purpose of combina- members increased
tion, or centralization, is to increase the efficiency of their by division
combined action : each of these—division of function and of labour and com-
combination of action—is necessary to the other, and is bination.
involved in the other.

From physiological division of labour follows definiteness Definite-
of the number, position, and form of parts.   Where every ness, a result of
part has its perfectly definite function, it follows that the division of labour.
number, form, and position of the parts must be definite.
We find that in the lower organisms the number of the
parts, especially, is often very indefinite ; but as we ascend
in the scale of organization this characteristic disappears.
Nothing, for instance, can well be less definite than the
number of leaves on a bough ; but in the flower, which is Leaves and flowers.
by far the most highly organized part of the plant, the
number of the petals and of all the other parts, in many
important classes at least, is perfectly definite.   And in
worms and millepedes the number of segments is inde- Worms, mille-
finite, being variable between different individuals of the pedes, and
same species; but among insects, crabs, and spiders, which insects.
are more highly organized on the same fundamental plan,
the number of segments is constant.

What precedes may be summed up by saying, that the Summary.
higher the organization the more complete are the *physio-*
logical division of labour, the *physiological centralization*,
and the *morphological definiteness*.

It would be impossible to give a full account of all the
tissues and organs which become distinct from each other
in the development of all the various classes of organisms,
without writing a complete treatise on comparative histo-
logy and anatomy.   But this is the place to describe in
outline the chief distinctions of the functions, and of the
corresponding organs, which we find in all organic forms,
except the very lowest.

The first and the only universal distinction of organs is Separation
that produced by the gelatinous matter which constitutes of internal

and ex-
ternal
parts, uni-
versal.
the whole substance of some of the lowest organisms
becoming more consolidated on the outside than in the
inside. Thus are produced the single cells of which
consist the Diatomaceæ among plants, and the Gromia
among animals; and there is probably no organism, not
even the Amœba, which does not present this character
in some degree. The higher organisms, as already stated,
consist (at least in great part) of masses of variously-
modified cells; and in them the external cells are usually

External
parts pro-
tective.
condensed into a comparatively denser and sometimes
hard tissue, the function of which is to protect the interior
organs; while the tissues of the interior, where the vital
processes go on, continue soft. So that in the highest
organisms and in the lowest alike the exterior parts are
consolidated, in order to protect the interior parts and hold
them together.

Separation
of nutri-
tive and re-
productive
organs, not
universal,
The next distinction that we meet in the ascending
scale of nature is that into the nutritive and reproductive
organs: in other words, into the organs which minister to
the life of the organism itself, and those which provide for
the existence of future organisms of the same kind. This
distinction is not absolutely universal among organisms:
among the Diatomaceæ and Desmideæ, which are very simple
forms of Algæ, the whole organism is capable of acting as
a reproductive organ, in a way to be hereafter described;
besides that many, probably all, of the lowest vegetables
and animals alike propagate their race by spontaneous
division into parts, a characteristic from which the Diato-
maceæ have their name.

and not
funda-
mental.
It is important to observe that the distinction between
the nutritive and the reproductive functions is not funda-
mental. The reproductive function is only a particular
form of the nutritive. Reproduction essentially consists,
as already stated, in separating from the organism a small
portion of formative material, or germinal matter, under
such circumstances as to enable it to build up a completely
new organism. But the properties of the germinal matter
which is thus detached for the formation of a new organism
do not essentially differ from the properties of the germinal

matter which is retained in the old organism, and ministers
to the growth or renewal of its tissues.

The next distinction is that into cellular structure, which Separation
is generally in animals, and probably always in vegetables, of cellular
that in which the nutritive processes are actively going on; lar struc-
and vascular structure, which, in its simplest form, consists tures.
of rows of cells which have been joined to each other by Cells unite
the removal of part of their walls (as rooms may be thrown to form
together by the removal of partitions), so as to form tubes vessels.
for the conveyance of nutritive fluids from one part of the
organism to another.[1]   Vessels are not needed, and con-
sequently they do not exist, in those organisms where all
the parts are alike in structure, and equally well situated for
obtaining nourishment. For this reason they are not found
among the Algæ, every part of which is able to derive its
nourishment separately from the water; but some rudiment
of vascular structure is found in all air-breathing plants,
except the simpler lichens and fungi,[2] in which any
movement of fluid that may be necessary takes place by
permeation.   For all tissues in which vital processes are
going on are permeable by water.

The reproductive organs, and the vascular or circulatory
organs, which are thus separated from the general nutritive
system, continue, notwithstanding, to form part of the
organs of *nutritive or vegetable life.* But in the animal
kingdom, and in a few instances in the vegetable kingdom
also, a still more profound distinction is established. We
have seen that all organisms transform matter and energy;
that the differentia of life consists in the power of effecting
a peculiar set of transformations of matter and energy. ·
The peculiar characteristic of animals, though some vege- Separa-
tables share it to a slight extent,[3] is the possession of a tion, in animals,

---

[1] The canals by which the substance of Sponges is traversed can
hardly be called structure at all ; and what they circulate is not sap or
blood, but only the water from which the sponge derives its nourishment.

[2] Carpenter's Comparative Physiology, p. 671.

[3] Cohn has found the structure of the filaments of the stamens of the
thistle to be closely analogous to that of involuntary muscle. For about
twenty-four hours the anthers, if touched, show a peculiar twisting
motion, and extrude pollen. (Medico-Chirurgical Review, January 1864.)

of nutritive and nervo-muscular systems.

distinct apparatus for the transformation of energy. This is the nervo-muscular system, which constitutes the organs of *animal life,* though none of these organs are to be distinguished in the very lowest animals.

A muscular system is found in some animals—among the *hydrozoa,* for instance—which have no rudiment of nerves; but the converse is not the case: there are never

Nerves are to muscles what vessels are to nutritive system.

any nerves except where there are distinct muscles. Nerves are to the muscular system what sap- or blood-vessels are to the nutritive system. The analogy is not close, but it is real. The function of the vascular or circulatory system is to increase the efficiency of the nutritive system by conveying nutritive material from one part to another; and *the primary function of the nerves is to increase the rapidity*

Internuncial function of nerves.

and precision of combined action among the muscles, and thereby to increase the efficiency of the muscular system by *transmitting stimuli from one part to another.* It was said long ago by John Hunter, that the primary function of

Helmholtz's experiment.

the nerves was *internuncial;* and Helmholtz has shown by a most ingenious experiment that some influence—in some respects like electricity, but not identical with it—runs along a stimulated nerve with a great but measurable velocity. On stimulating by electricity a piece of muscle taken from a newly-killed frog, the muscle contracted. On applying the electric stimulus, not to the muscle itself, but to the loose end of a nerve in connexion with the muscle, the muscle again contracted; but between the application

Velocity of nervous stimulus measured.

of the stimulus to the one end of the nerve and the contraction of the muscle at the other end a time elapsed which, though quite too short to be perceptible to the eye, was measured by the delicate apparatus employed by Helmholtz, and enabled him to estimate the rapidity of the transmission of impulses along the motor nerves of the frog at from 81 to 126 feet per second.[1]

Nerves, probably, transmit energy.

But what is it that is transmitted along the nervous fibres? I think it is scarcely possible to doubt that it is

[1] Carpenter's Human Physiology, pp. 473, 474. It would be nearly impossible to explain the apparatus by which the time is measured, without a diagram. Of course it is electrical.

some form of vital energy. If so, there is this remarkable parallelism: that the function of the nutritive system is to transform matter, and of the muscular system to transform energy; the function of the vessels is to convey matter, and that of the nerves to transmit energy.

I must, however, state, in order to avoid a possible mis- conception, that the energy put forth by any muscle is not brought to it by its nerves, but transformed into motor energy by the muscle itself. There may possibly be excep- tions to this in the constantly-working muscles of the heart and lungs; but it is certainly true of the voluntary muscles, as is shown by the familiar fact, that fatigue is felt most in those muscles that have been most overworked. The relation of the nerves to the muscles may be compared with the relation of the mind of the master who gives orders, to the muscular force of the workmen who execute the orders. Each muscle usually transforms energy for itself.

It ought also to be observed, that in the well-known experiment of making the cut-off legs of a frog kick by means of an electric stimulus, the electricity is a *mere* stimulus, an exciter to action, but does not supply the motive power; the motive power is obtained by the trans- formation of vital energy, as in the living frog. The proof of this is, that the cut-off legs *become fatigued* with repeated stimulation, and respond less forcibly, but recover their power when laid by for a time, which would not be the case if the motive power were supplied by the transforma- tion of the electricity. Of course the same applies to the muscle and nerve in Helmholtz's experiment.

Where there are no nerves, as in the *hydrozoa*, the muscular tissue has itself the power of transmitting sti- muli: thus, if one of the tentacles of a *hydrozoon* be irritated, not only that tentacle but the others will contract. In this class, however, the propagation of the stimulus is relatively slow, and, consequently, if one tentacle is irritated the rest will contract but slowly. The *bryozoa* are a mol- luscan or molluscoidan class, adapted to the same kind of life as the *hydrozoa*, but with a totally different anatomy, and a discernible, though rudimentary, nervous system; Hydrozoa and bryo- zoa.

and among them, if one tentacle is irritated, the rest will contract instantaneously.[1]

As already stated, the parts of organisms in which nutritive processes go on (as, for instance, young buds, animal and vegetable embryos, and secreting organs) mostly consist of cellular tissue; and vascular structures, among vegetables certainly,[2] and probably among animals also, consist of modified cells. This is shown both by the *Develop-* history of their development among the higher vegetables, *ment of vessels out* and by the fact that among the higher fungi and lichens *of cells.* we meet with cells elongated in the direction of the length of the stem, which are evidently a transition from simply cellular to vascular structure.[3] Cellular and vascular structures are thus probably akin; and the parallel relation *Resem-* between muscle and nerve is, I think, shown (though I do *blance of nervous* not wish to lay any stress on this) by the resemblance of *fibre to* the minute structure of nervous fibre to that of muscular *muscular.* fibre.[4]

But the parallelism of the circulatory and nervous systems is far more unmistakeably shown in various other *Blood-* ways. The nerves and the blood-vessels resemble each *vessels and* other in ramifying and inosculating[5] throughout the entire *nerves ramify.* body; and also in this, that the action of both is in a great degree (though, as careful researches have shown, not absolutely) controlled by great central organs; the circulatory *The heart* system by the heart, and the nervous system by the brain. *and the brain.* Circulatory centralization and nervous centralization, as they may be called, are seen to increase together as we ascend in the animal scale: that is to say, the higher is the organization of any animal, the more complete is the centralization both of its circulatory system, and consequently of its nutritive or vegetative life,—and of its nervous system, and consequently of its animal life. It is

[1] Spencer's Principles of Biology, vol. ii. p. 368.   [2] Ibid. p. 264.

[3] Carpenter's Comparative Physiology, p. 671.

[4] For the fact of this resemblance, see Beale's edition of Todd and Bowman's Physiology, p. 72.

[5] To inosculate means to reunite after ramifying. But though nerve *trunks* ramify and inosculate, it is believed that the ultimate nerve-*fibres* remain always distinct.

a most interesting instance of this, that the *amphioxus*, a Amphi-
species of fish which is the lowest of all vertebrates, is at oxus.
once without a brain, though it has a spinal cord, and
without a distinct heart, instead of which it has several
pulsating enlargements of the blood-vessels.[1] These two
characters make it quite unique among vertebrates, and
probably show that it is a link between the vertebrates
and some now lost class of low organization.

The parallelism between the circulatory and nervous Blood-
systems is further shown in this, that those parts of the vessels and
nerves are
body which are the most abundantly supplied with blood- abundant
vessels are also the most abundantly supplied with nerves ; in the same
places.
and the nails and hair, which have no supply of blood at
all, are also without nerves.[2] The activity of the two is Their
action is
heightened or lowered together. The vessels of inflamed heightened
parts are unusually full of blood, and the action of their together.
nerves is heightened : this last is proved by increased Inflamma-
tion.
sensibility, and also, as I have shown reason for believing,
by elevated temperature.[3] And, what is a parallel fact to
this, the blood-vessels of the brain are comparatively empty
during sleep, which essentially consists in a lowered action Sleep.
of the brain ; and the same is true of the blood-vessels of
the retina.[4] It is possible to lower the nervous activity so Want of
fresh blood
as to destroy the sensibility of any part, by tying the causes in-
arteries so as to deprive it of its supply of fresh blood.[5] It sensibility.
belongs to this class of facts that the heart, which is the Connexion
of heart
central circulatory organ, is more easily acted on by nervous with
influence than any of the other organs of the vegetative brain.
life.[6] The susceptibility of the heart to influences arising
from the emotions has caused it, indeed, in popular
language, to be regarded as their seat.

We have seen how dependent is the activity of the Depend-
ence of
nervous system on the supply of blood. But the converse nervous
is not true : the activity of the circulating system does not action on

---

[1] Carpenter's Comparative Physiology, p. 447.
[2] Carpenter's Human Physiology, p. 604.
[3] Ibid. p. 99.   [4] Ibid. p. 590.
[5] Carpenter's Comparative Physiology, p. 175.
[6] Claude Bernard, in *Revue des Deux Mondes*, 1st March, 1865.

circula-
tion not
reciprocal.

in any similar way depend on nervous agency. Thus, as
just stated, the nerves of a part are paralysed by tying the
artery that supplies it; but the circulation of a part is not
paralysed by cutting the nerve-trunk that supplies it.

Opposite
relations
of blood
and nerve
to muscle.

Recent experiments on cold-blooded animals have shown
a very remarkable contrast between the relations of blood
and nerve to muscular fibre. We know that the stimula-
tion of a nerve tends to cause the muscle in connexion
with it to contract. It is now ascertained that the supply
of fresh arterial blood tends to cause the muscles that it
bathes to retain the elongated state; and when the supply
of blood is cut off, the muscles tend to contract spon-
taneously.[1] In other words, blood tends to keep the
muscles elongated and relaxed, and nervous action makes
them contract. To state these facts in the language of the
dynamic theory :—The blood undergoes oxidation in the
lungs: in the process of oxidation energy is liberated,
part of which is carried by the blood to the muscles, and
supplies them with their charge of static vital energy.[2]
So long as they remain elongated, the muscles retain this
charge of static vital energy; but when a nervous stimulus
comes and makes them contract, this vital energy is
transformed into motor energy.

It is to be observed, that the elongated or relaxed state
of a muscle is that in which it contains a charge of energy,
and the contracted state is that in which the energy
has been parted with. This distinction is one on which
emphasis must be laid, for it is very important, and by no
means obvious. It is totally unlike that which obtains in
an elastic body, such as an india-rubber cord; for the
india-rubber contains a charge of energy while it is strained,
but none while it is relaxed.

It is also proved by the foregoing facts that the blood

[1] See Dr. Norris's Report on Muscular Irritability, British Association
Report, Nottingham, 1866. This law, I believe, was first stated by
Dr. Radcliffe. (Carpenter's Human Physiology, p. 680.)

[2] See p. 97. The theory that the motor energy produced by any muscle
is due to the oxidation of that muscle at the very moment, is, I think,
conclusively disproved by the experiments of Fick and Wislicenus. (See
Philosophical Magazine, June 1866.)

supplies the various parts of the body with energy as well as with matter. The nerves, of course, transmit energy only. ` ´

What has been said on the direction of animal development may be thus summed up :—

Every organism transforms both matter and energy, and it is probable that every living part of an organism always continues to transform them both. But the characteristic of animal development is, that one set of organs—the nutritive—is specially appropriated for the transformation of matter; and another—the nervo-muscular—for the transformation of energy. The nutritive, or vegetative, system of organs is for the most part internal, and the characteristically animal organs—those of the limbs and mouth, with their muscles—are external to the nutritive. In both vegetables and animals, a vascular, or circulatory, system is developed, the function of which is to minister to the nutritive life by the circulation of nutritive fluid; and in animals a nervous system is developed, the primary function of which is to ensure the harmonious and efficient action of the muscular system, by the transmission of stimuli from one part to another.

The foregoing account of the relation of nerve to muscle, however, would be most imperfect were it not mentioned that nerve-fibres never exist without ganglia, which are situated at the junctions of the fibres, and from which the fibres radiate throughout the body. The action of ganglionic tissue is even more mysterious than that of nerve-fibre. It appears, however, to be a universal law that one fibre can communicate a stimulus to another only through a ganglion. In the higher animals, sensation and thought are produced in some altogether inscrutable way by the mutual action of the ganglia and the nerve-fibres: sensation can be produced neither in a ganglion unless it is acted on by a nerve-fibre, nor in a nerve-fibre unless it is in communication with its ganglion.

NOTE.

THE FUNCTIONS OF THE NERVOUS SYSTEM.

Lewes's theory of sensation

MR. LEWES, in an admirable treatise on nervous action, which forms part of the second volume of his "Physiology," has advanced the opinion that all mutual action of ganglia and nerve-fibres is accompanied by sensation. He thinks the action of the visceral nerves, of which we are unconscious, goes to make up the sense of being alive. This theory is plausible, and it might

disproved. appear impossible to prove it wrong; but I think it is disproved by the fact, that cases of blindness have been observed in which, though there is total insensibility to light, the pupil continues to contract in light and expand in darkness.[1] There are special nerves for this expansion and contraction; and the fact just quoted, I think, proves their action to be quite independent of sensation.

Impossible to say where sensation begins.

This instance, and many others, though I know of none so striking and conclusive, show how impossible it is to determine where sensation begins; and if a large part of man's nervous system is insentient, it does not appear anomalous or improbable that the whole nervous systems of the lower worms and mollusca should be so. I believe the most probable guess we can make is, that in the ascending scale of organization sensation begins with the first appearance of organs of special sense; and the most generally distributed organs of special sense among animals appear to be the eyes.

It has been often repeated that the ganglia are generators of nervous energy, and the nerve-fibres its conductors. I agree with Mr. Lewes, however, that this account of the matter is,

Nerve-fibre may act without ganglionic influence.

at least, insufficient. A nerve-fibre is capable of acting even when it is not in communication with a ganglion; as is proved by the well-known experiment of making the cut-off leg of a frog kick by means of exciting its nerve with electricity, and also in the experiment mentioned in the foregoing chapter, by which Helmholtz has measured the velocity of the nervous current.

[1] Carpenter's Human Physiology, p. 533.

CHAPTER XIII.

ORGANIC SUBORDINATION.

WE have seen in the last chapter, that the highest
organic development is the most complete physiolo-
gical division of labour, and the most perfect physiological
centralization. In the lowest organic species, and in the
germs of the highest, the parts are all alike and all inde-
pendent of each other; in the mature forms of the highest
species the parts are all different, and the whole organism Organic
is bound together into one system, with all its parts differenti-
ation and
mutually dependent. To speak technically, organic pro- integra-
gress consists in increasing *differentiation* and increasing tion,
integration.[1]

Besides these, there are within the organism relations
of *dependence* and of *subordination*, which I have now depend-
to describe. Before stating the relation of organic de- ence and
subordina-
pendence, I must go back to the inorganic sciences. tion.

Whatever exists, so far as is known, or can be known, Space and
to us, exists in space; and whatever acts, acts in time. time are
conditions
Consequently the properties of space and time are con- of all
ditions of all existence and of all action; the laws under things.
which things exist and act cannot be proved, nor even
stated, without express or implied reference to the properties
of space and time. It results from this, that mathematics, Conse-
which is the science of the laws of space and time, is the quently
necessary ground of physical science. To take the very mathema-
tics is the
simplest instances: it would be impossible to prove, or ground of
even to state, the law of the parallelogram of forces, unless physical
science.

---

[1] The word *differentiation* is now generally used in this sense. *Integration*
is a parallel word to it, and is used in Spencer's Biology.

L

the geometrical properties of the parallelogram were known; and it would be impossible to prove, or to state, the law that the energy due to a moving body is proportional to the second power of its velocity, unless the nature of powers and roots were known. Mathematics is thus necessary as a foundation for dynamics.

Dynamics, the basis of physical science. Among physical laws, the most general are those of force: the laws of force, or, as they are generally called, the laws of motion, are the only laws which are true of all action whatever. Consequently, dynamics is necessarily the basis of physical science: or, in other words, the theory of force is necessary as a basis for the sciences of material things.[1]

Secondary dynamical sciences. The sciences of sound, radiance, heat, electricity, and magnetism, are merely particular cases of dynamics, being applications of the theory of force to special kinds of actions.

The laws of force apply to all the actions of all matter; but there is a great variety of laws that apply only to those actions, or functions, which are characteristic of particular Chemistry. kinds of matter: I mean the laws of chemistry. The laws of chemistry depend on those of heat and electricity in a very great degree; so decided indeed is the dependence, that it would be impossible so much as to state many of the most important chemical laws, unless the elementary laws of heat and electricity were taken as known.

Biology. Finally, the properties of living organisms, and their peculiar actions, in a great degree depend on the general properties of force, and on the special properties of the chemical substances of which the food of the organism, and the organism itself, are composed. Vital properties are certainly more than mere resultants from physical and

---

[1] It may be said that I contradict myself in calling mathematics the *ground* of physical science, and dynamics its *basis*. There is, however, no contradiction. Dynamics is a part of physical science, but mathematics is not. Physical science is built on mathematics, as a building on the ground; the other parts of physical science are based on dynamics, as the higher parts of a building on its base.

I attach no importance to these metaphors, but I wish to show that I have not fallen into any inconsistency.

chemical ones, but life does not suspend the ordinary physical and chemical properties of the substances in the organism; on the contrary, it works through them. Consequently, the action of life depends on the properties of the materials it has to work with; and it is impossible to understand the nutritive functions of organisms, without some previous knowledge of chemistry. It would have been impossible, for instance, to explain the nature of respiration, which is a slow combustion, unless the nature of combustion had first been discovered.

So that we have this series :—

1. Mathematics, or the science of the properties of space and time. Series of sciences,

2. Dynamics, or the science of the laws of force in general.

3. The secondary dynamical sciences, being those of sound, radiance, heat, electricity, and magnetism; all of which are particular applications of dynamical theory.

4. Chemistry, or the science of the special properties of particular kinds of matter.

5. Finally, biology, or the science of the properties of living beings.

In this series, each member is dependent on that which goes before it, but independent of that which comes after it. Biology is dependent on chemistry, because the actions of life on the substances in the organism cannot be understood, unless the properties of the substances themselves are known first. Chemistry is dependent on the secondary dynamical sciences, because its laws imply those of heat and electricity, and could not be understood without them. The secondary dynamical sciences are dependent on general dynamics, of which they are but particular cases. And lastly, dynamics depends on mathematics, without which it cannot make a single step in reasoning. each dependent on the preceding.

This dependence is not reciprocal. The truths of mathematics do not in any way depend on those of dynamics for their proof. The truths of general dynamics are true, independently of those of the secondary, or special, dynamical sciences. The laws of the secondary dynamical Dependence not reciprocal.

sciences are true independently of those of chemistry, and can be understood without them. And the laws of chemistry are true, independently of those of life, and can be understood without them.[1] Thus the series resembles a building of several stories, each of which rests on that below it.

Depend-
ence is not
only of the
sciences,
but of the
things.

Although, in order to avoid circumlocution, I have spoken of the sciences as depending the one on the other, yet in reality the dependence is not only of the sciences, that is to say of our knowledge of the laws, but of the laws of the things themselves. Not only our knowledge of biological laws, but the biological laws themselves, depend on chemical laws. Not only our knowledge of the chemical laws, but the chemical laws themselves, depend on the laws of heat and electricity. The laws of heat and electricity are but cases of the laws of general dynamics. And not only our knowledge of the laws of dynamics, but the laws of dynamics themselves, depend on the laws of mathematics, which are but the statement of the properties of space and time. I am not here insisting, as may perhaps be thought, on a merely identical, or self-evident, proposition. It is quite easy to conceive such a relation between two sciences, that our knowledge of the one shall be dependent on our proficiency in the other, without the subject-matters of the two having any connexion whatever. Such a relation does exist between optics, or the science of light, and histology, or the science of the minute structure of organic tissues. Histology has been created as a science by the microscope, which owes

Accidental
connexion
of histo-
logy with
optics.

---

[1] It may be objected, that this is wrong in point of fact : it may be said that chemical laws are implied in the theory of electric currents, and biological laws in organic chemistry. I reply, that electro-chemistry does no doubt imply chemical laws, and may be regarded as a branch of chemistry, but the whole theory of electro-statics and electro-dynamics may be stated without any chemical knowledge being needed. And as to organic compounds, chemistry works with them just as if they were mineral substances.

Of course the various sciences run into each other, and have many and varied mutual relations. But I think they are more distinct, and stand in simpler relations to each other, than we might have anticipated.

its existence to the advance of optics; and yet the subject-matters of optics and histology have no connexion whatever. But such a connexion is merely accidental and instrumental: the connexion of the sciences in the series which I have drawn above, on the contrary, is logical and real, and is based on the dependence of the things themselves.

So far, as the reader will perhaps have perceived, I have Obligation taken these ideas about the dependence of the properties of to Comte. things, the one on the other, from Comte's Positive Philosophy.[1] What follows, though I claim no originality for its substance, has not, so far as I am aware, been stated in a systematic form before.

We have seen that in inorganic nature, and up to the Depend-laws of life, there is a relation of dependence of the laws ence of vital laws of one science on those of another, which dependence is one on the not reciprocal. The same relation is continued between other. the different laws of life: animal or motor life depends on Vegeta-vegetative or nutritive life; and mental life depends on tive, animal, animal life. And among these also, the dependence is not and mental reciprocal: vegetative life may exist without animal life, life. and animal life may exist without mental life. Mental life depends on animal life, and animal life depends on vegetative life, just as vegetative life depends on chemical properties, and chemical properties depend on those of heat and electricity. These are facts of observation. Throughout the whole vegetable kingdom we see vegetative life without animal life; and throughout a great part of the animal kingdom, we see very energetic animal life with scarcely a trace of mental life. But the converse is impossible; there is not, nor under the laws of life can there be, any such thing as animal life without vegetative or nutritive life for its basis; or mental life, without animal life as its basis. It is a consequence of this relation, that

---

[1] See Harriet Martineau's condensed translation of Comte's Positive Philosophy, vol. i. chap. ii. I have read Comte only in the above-mentioned translation, which I believe is thoroughly trustworthy. The series I have drawn in the text differs from Comte's in detail, but is the same in principle.

the animal life may be almost, if not totally, suspended in

Sleep.   sleep, but the vegetative life cannot be suspended for a
moment without death. And another very remarkable

Experi-   consequence of the same relation has been experimentally
ment.   ascertained; namely, that it is possible to extinguish the
mental life, and in a great degree the animal life of an
animal, by removing the parts of the brain that minister
thereto, while the organs of the vegetative life continue to
perform their functions for a considerable time. Of course
in this experiment, as well as in sleep, the involuntary
muscles of the heart and lungs continue to act, as on their
action that of the vegetative life depends.

The series   We may now thus continue the series that we saw to
continued. exist from the laws of space and time up to those of life,
so as to include the three ascending degrees of life itself;
each term of the series being dependent on those which
go before it, but independent of those which come
after it:—

1. The properties of space and time : mathematics.

2. The laws of force : dynamics.

3. Special cases of the laws of force : sound, radiance,
heat, electricity, and magnetism.

4. The properties of particular kinds of matter:—
chemistry.

5. The laws of vegetative life.

6. The laws of animal life.

7. The laws of mental life.

But though the dependence of animal life on vegetative
life is of the same kind with the other laws of dependence
that I have stated, yet it is not practically possible to treat
of them apart, as the subjects of distinct sciences. The
old distinction of zoology and botany must no doubt be
always necessary in classificatory, or what are called sys-
tematic, works; but it would be impossible to treat the
physiology of the vegetative life, and that of the animal
life, as distinct sciences. With the laws of mental life it
is different. They may in a great degree be adequately
treated of apart; and I intend in this work to follow the
usual practice, and to keep psychology, or the science of

mind, as distinct as possible from biology, or the science of life. At the same time I avow my opinion—though it is, perhaps, only a question of words—that psychology is really a branch of biology.

We have seen that the relation of *dependence* of one group of properties, or functions, on another, holds both in inorganic matter and in life. But when we come to vital functions, we find a different though parallel relation, unlike any in the inorganic world. I mean the *subordina-* Subordination of one function to another : one function working tion of through another. As I have already stated, life acts functions. through the physical and chemical properties of matter; and it is equally true that the conscious, or vital functions, or those of the mind, act through the unconscious ones. These statements may need explanation.

Life, as I have stated before, does not suspend the Matter ordinary laws of matter and energy; life works in accord- subordinate to life. ance with those laws and through them, directing their forces to the attainment of ends which they would not have attained of themselves. Thus, though life is so completely *dependent* on the ordinary properties of matter that it could not exist, nor even be conceived to exist, without them; yet life makes those properties *subordinate* to its own purposes. Exactly parallel to this is the relation of the mind to the unconscious life. The mind is *dependent* for its existence on the unconscious life : mind is a function of the nervous system; and the primary purpose of the nerves, as we have seen in the last chapter, is to enable the muscles to work together. But mind has the power of Uncon- making the unconscious life *subordinate* to its purposes. scious life subordinate to mind.

This last statement will perhaps be scarcely intelligible. nate to It may be thought that whether the mind works alone, in mind. thought,[1] or through the body, in voluntary muscular action, all mentally directed action is conscious; and that the only unconscious life is the vegetative life, which is not under the direct control of the mind at all. This, however, would be a mistaken view. Paradoxical as it may sound, it is a

---

[1] This expression is not strictly accurate. I shall have to show farther on, that all mental action is connected with bodily action.

Muscular action essentially unconscious.   simple truth, that muscular action is itself unconscious. We produce the motion of a particular set of muscles—those of the legs, or hands, or mouth, for instance—by a conscious mental determination; we become aware that they move as we intend, by means of the "muscular sense," which is produced in muscles by their action. But between the conscious mental determination and the sense of muscular action, there is an intermediate link of which we are utterly unconscious; namely, the special combination of muscles which is needed to effect the movement we intend. Of this we know nothing whatever except what anatomy teaches us; we effect these combinations by a perfectly unconscious instinct. Were consciousness of the required muscular combinations necessary before we could make the combinations, in the same way that, for instance, consciousness of the meaning of words is necessary in order to use the words with accuracy, we could not perform any muscular movement until we had learned the anatomy of the muscles.[1] It is indeed scarcely a metaphor to say that the brain gives its orders to the muscles without knowing the details of the way in which its orders are to be executed. An equally clear proof of the essentially unconscious nature of muscular action is afforded by the fact, that when any set of muscles, especially those used in walking, is set in motion by a determination of the will, and the attention afterwards withdrawn from their action in consequence of the mind falling into a state of abstrac-

Instance in reverie.   tion or reverie, the action of the muscles often continues independently of consciousness or will. And, what is a fact of the same kind, if nervous connexion between the brain and the lower extremities is cut off by accidental injury to the spine in man, or by purposely cutting through the spinal cord in an animal, irritation applied to the feet causes no sensation, but produces convulsive movements in the legs, of which the patient is unconscious.[2]

Summary.   To sum up what has been said:—The higher functions are *dependent* on the lower ones; the vital functions are dependent on the inorganic, and the conscious, or mental

---

[1] Carpenter's Human Physiology, p. 559.   [2] Ibid. p. 529.

functions, on the unconscious; but this dependence is not .
reciprocal. And the lower functions are *subordinate* to the
higher ones, which work through them; the unconscious
functions are subordinate to the conscious, and the inorganic
functions to the organic; and this subordination never
becomes reciprocal.

It is to be observed that the dependence of functions Depend-
one on the other is necessary and constant; the conscious ence neces-
functions are always and necessarily dependent on the ordination
unconscious ones, and life is always dependent on matter. not so.
But the subordination of functions one to the other is
neither necessary nor constant; the mind often loses its
control of the body, and life often loses its control of matter.
When the control of the higher functions over the lower,
and the subordination of the lower to the higher, are
weakened, the result is disease; when they are destroyed,
the result is death.

CHAPTER XIV.

ORGANIC FUNCTIONS.

Classification of organic functions. IN the last chapter I have classed the organic functions as vegetative, or nutritive; animal, or motor; and mental. The vegetative and animal functions I have classed together as unconscious, in opposition to the mental, which are conscious. These distinctions may be most conveniently stated in the following tabular form :—

Unconscious functions $\quad . \left\{ \begin{array}{l} \text{Vegetative, or nutritive.} \\ \text{Animal, or motor.} \end{array} \right.$

Conscious functions $\quad . \quad .$ Mental.

Different classifications for different purposes. In speaking of the same subject, however, it is often necessary to adopt different classifications at different times, according as we regard it from different points of view. That adopted above shows the relations of the different vital functions as made known from the common, practical point of view of every-day and every man's consciousness, which begins with the distinction between the body and the mind. This point of view is no doubt insufficient, and its results need to be corrected by comparison with those obtained from other points of view. We are so constituted and so circumstanced, in the intellectual as well as in the physical world, that the observations taken from any single point of view are necessarily incomplete, and need to be supplemented by others. But, though incomplete, they are true so far as they go, and are untrue only when they are mistaken for the whole truth.

In the present chapter, I shall adopt a classification of organic functions which is not based, as the former one

was, on their obvious connexions. That which I am going
to use is intended, on the contrary, to explain the way in
which one function is developed out of another. The law
of the development of organisms, as we have seen, is that
they are developed out of simple germs, and that the parts
are gradually differentiated the one from the other. The Development of
same is true of functions;—functions also are developed by functions
gradual differentiation. I may not, perhaps, be able to by differ-
make this last statement perfectly intelligible, until I come entiation.
to the subject of mental science; it is, however, implied in
the views I have to state in this chapter.

We have seen that all organisms transform matter and Their clas-
energy. The transformation of matter is the peculiarly sification
on this
nutritive, or vegetative, function; the transformation of basis.
energy is the peculiarly animal function, and is generally
motor—that is to say, the energy is generally transformed
into motion, though in particular cases it is transformed
into heat, electricity, or light.

Let us speak of the vegetative functions first. The Vegetative
functions
primary vegetative function, which is the ground and con- chemical,
dition of all other vital functions whatever, is the decom-
position, by plants, of water and carbonic acid, and the
formation of organic compounds. This function is in its
results a purely chemical one, though it produces combina-
tions which, as I believe, no chemistry but that of the
living vegetable organism can possibly produce.[1]   The
power of decomposing carbonic acid, and probably of de-
composing water also, is peculiar to the vegetable king-
dom, though not universal in it.[2]   Animals cannot decom-
pose carbonic acid, and consequently cannot form the
primary, or first-formed, organic compounds for them-
selves; but they effect various transformations in the
organic compounds which they receive in their vegetable
food. Some of these transformations may perhaps be due
to the ordinary chemical forces, acting as they might act in
a laboratory; but some are certainly due to a peculiar vital
action, controlling the chemical forces. This is eminently
the case in secretion: one set of secreting cells separates

[1] P. 86.   [2] See Note A at end of this chapter.

bile from the blood, another milk, and so on; for these various results are affected by glands, all of which consist of substances of the same chemical constitution; and consequently would all act alike, if their action were merely a chemical one.

and struc-
tural.   The next vegetative function consists in the arrangement of the organic compounds so as to form tissue. As already
Cellular stated, the simplest tissues are cellular, and cell-formation
tissue. consists in the separation, or differentiation, of the primary structureless germinal matter into consolidated substance, which forms the outside of the cell; and soft, almost fluid, substance which constitutes the cell-contents, and, at least in the simplest organisms, retains the properties of germinal matter. Many organisms, as for instance the lowest Algæ, consist of but a single cell, which propagates by spontaneous division. But in others the cells, after dividing, do not separate, but remain together; and thus cellular tissue is formed. The unicellular and multicellular forms of Algæ graduate into each other, and the Algæ in general consist of a mass of cellular tissue, with little further differentiation.

Cells, in the various parts of various organisms, undergo endless modifications, both in form, and by acquiring the power, as stated above, of separating different substances
Differen- from the sap or blood. Accordingly, the next differentia-
tiation of tion consists in the acquisition of different characters by
tissues. different masses of cells, so as to form different tissues : as, for instance, soft leafy substance and hard woody fibre, in plants; and muscle, nerve, and bone, in animals.

Growth The formation of tissues constitutes growth, and the
and deve- differentiation of tissues the one from the other constitutes
lopment development. It is important to observe that growth and
antago- development are not the same thing; they do not imply
nistic. each other, and do not necessarily go on together—indeed, there is frequently an antagonism between them; rapid growth and rapid development appear, at least in certain
Leaves and cases, to be incompatible. Thus, flowers are more highly
flowers. developed than leaf-bearing branches; and flower-bearing branches are always found to have lost something of the

indefinite power of growth that belongs to leaf-bearing
ones, and if they are supplied with abundant nourish-
ment, so as to cause them to grow rapidly, they cease to
bear flowers, and are changed back into leaf-bearing
branches. A still more remarkable instance of the same
kind is that of the worm-like larvæ of some insects, which Insect
at first feed voraciously and grow rapidly, forming com- metamor-
paratively simple and undifferentiated structures: but phosis.
growth ceases when further development begins; growth
ceases when the larva enters into the chrysalis state, and
all the vital energies are employed in the work of develop-
ment, which consists in transforming the comparatively
undifferentiated tissues of the larva into the highly differ-
entiated tissues of the perfect insect. And not only so,
but the insect becomes inactive: motion ceases as well as
growth, in order apparently that no energy may be spared
from the work of development. As already remarked,[1] it
is nearly impossible to doubt that some transformation Transfor-
of energy takes place in the act of development. If it is mation of
energy in
true that a charge of energy is taken up and becomes develop-
static in the act of unorganized material acquiring organi- ment.
zation, it appears probable that a further charge is taken
up in the act of development, which is the acquisition of
higher organization.[2]

The tissues which are differentiated from each other Formation
combine into organs. In some cases at least, there is no of organs.
distinction between tissue-formation and organ-formation.
The shell of a mollusc, for instance, is at once a peculiar
tissue and a peculiar organ. But in the highest organiza-
tion, each tissue is found in many organs, and each organ
consists of many tissues. Muscle, nerve, and bone, for

---

[1] P. 107.

[2] If I understand Dr. Beale, he believes rapidly-growing morbid growths,
of the cancerous type, to be caused by cellular growth being in such excess
as to destroy the power of development. (See Beale's edition of Todd and
Bowman's Physiology, pp. 92, 130.) It is known that cancer consists of
"fungous" cellular tissue of very low organization. It is very interesting,
and to my mind satisfactory, thus to find this most fearful of all classes
of disease traceable, like commoner diseases, to a disturbance in the balance,
or harmonious action, of the different vital functions.

instance, are found alike in the head, in the limbs, and
along the spine of man. It is self-evident that the forma-
tion of organic compounds must be anterior to any forma-
tion of tissues or organs. But it cannot, I think, be said
that the formation either of tissues or of organs is in any
sense anterior to the other. It is to be remembered also,
that, as already stated, there are some tissues, at least in
animals, which do not originate in cells, but are formed
by the direct transformation of structureless sarcode.[1]

Classifica-
tion of
vegetative
functions.
From the point of view which I have taken in the last
few paragraphs, the vegetative functions may be clas-
sified as

> Formation of organic compounds;
> Formation of tissue; and
> Formation of organs:

of which the first is chemical, and the others may be called
structural.

Animal
functions.
We now come to the animal functions, which essentially
consist in the transformation of energy.[2] As I aim only
at drawing an outline, not at filling it up (which, indeed,
in the present state of science, no one, probably, is com-
petent to do), I will say nothing of the production of heat,
electricity, and light by animals; I will speak, as I did in
the last chapter, only of the motor functions, which are
the characteristic ones of unconscious animal life: and of
the sensory, conscious, and mental functions.

Four
grades of
the motor
function.
In the ascending scale of nature, there are four grades
of the motor function, differing from each other according
to the circumstances under which the transformation of
vital into motor energy is determined.

Sponta-
neous
motion.
The first of these may be called the spontaneous. To
this class belong the circulation, or rather rotation, of the
almost fluid contents of vegetable cells, which is often to
be seen under the microscope: the motions of the germs
of low aquatic organisms, vegetable as well as animal,
through the water (which have often caused them to be

[1] P. 127.

[2] See the chapter on the Dynamics of Life (Chapter X.) for the relation
between conscious nervous action and the transformation of energy.

mistaken for microscopic animals), and that "ciliary" motion, which is the only motor action of sponges, and appears to be universal in the animal kingdom. Motions of this class are found where there is no nervous system, as in plants and sponges: and even where there is a nervous system they are quite independent of nervous agency, as is proved by the fact that the "cilia" in man Cilia. and the higher animals continue in motion long after death, and even when they are detached from the body. So far as has been ascertained, they are also independent of any structure, but are simply due to the primary power of living matter to transform energy. No structure has been as yet discovered in the "ciliated cells" of even the highest animals.[1]

The next kind of motor action is that which is per-Motion in formed in response to a stimulus, and not accompanied response to a stimulus, with sensation. This is generally confined to animals, though there are instances of it among plants, as in the in plants: sensitive-plant and in Venus's fly-trap. The fact that it is found-among vegetables at all proves that it cannot be essentially dependent on nervous action; and a similar proof is afforded by the Hydrozoa among animals, which have no in animals vestige of a nervous system, yet spontaneously close on without nerves: their food when it touches the tentacles. And all muscular fibre appears to have the power of contracting in response to various kinds of stimuli, such as electrical excitement,[2]

---

[1] Carpenter's Comparative Physiology, p. 125. See also Carpenter's Human Physiology, p. 674.

Cilia are minute hair-like projections, which are in constant and rapid motion during life. Their use varies according to position : in animalcules and in the Ciliograda they are organs of motion ; in very many animals they are used to produce currents in the water, sometimes for the purpose of bringing food, sometimes to keep the respiratory organs bathed with fresh supplies of water. In land animals, their only known function is to produce currents of fluid towards the outlets of the body. If cilia are to be called organs, they are organs the formation of which is independent of any differentiation of the tissue.

[2] Thus in Helmholtz's experiment (p. 138) to determine the velocity of the nervous current, electricity is seen to be capable of acting on muscle directly, as well as of acting on it through the means of nerve ; causing the muscle to contract in either case.

the application of some poisons, as well as to the stimulus
through of a flow of nervous energy. But where there is a nervous
nervous system all muscular action appears to be normally pro-
agency. duced by nervous agency. This is true even of the action
of the heart, which has a nervous system of its own.
When motion takes place in response to a stimulus and
through nervous agency, the mechanism is as follows :—
Nervous Every nerve-fibre is connected—at least at one extremity
mecha-
nism. —with a ganglion. Different nerve-fibres have different
functions, according to the organs with which they are
connected at their *outer* terminations (their ganglia being
Two sets called their *inner* terminations) : some are *centripetal*, and
of nerves. transmit stimuli from without inwards to their ganglia ;
others are *centrifugal*, and transmit motor impulses from the
ganglia outwards to the muscles.[1] All motor action which
is determined by nervous agency is a complex fact, in-
volving the participation of at least two nerve-fibres and a
ganglion. When motion is caused by a stimulus, the
stimulus—which may consist, for instance, in the contact
of something that irritates the skin, or in the presence of
food in the mouth—produces a flow of nervous energy
along the nearest centripetal fibre to its ganglion. The
ganglionic cell that receives the stimulus communicates it
to another cell in the same ganglionic mass, or to another
ganglion. Some action takes place among those cells,
which determines the flow of a current of nervous energy
outwards from the ganglion, along a centrifugal or motor

---

[1] *Centripetal* and *centrifugal* are, I think, better words than *afferent* and
efferent, which Dr. Carpenter uses.

It is doubly inaccurate to use the words sensory and motor in this sense.
All the sensory nerves are no doubt centripetal, but the facts of reflex
action stated in the text show that there are centripetal nerves which are
not sensory. And though centrifugal nerves are necessarily motor, yet
they may be sensory nerves also. I agree with Mr. Lewes in thinking it
most probable that the motor nerves are the seat of the muscular sense,
or sense of muscular action. Thus some centripetal nerves are sensory,
and others are not ; while all centrifugal nerves are motor, but some are
sensory and others are not ; for the action of a voluntary muscle is
accompanied by the muscular sense in its nerves, but the action of the
muscles of the heart and stomach, in health at least, produces no
sensation.

fibre to the muscle in which the motion is to be produced,
in order to make the right response to the stimulus.

Such actions as these are called reflex, the nervous Reflex
action being, as it were, reflected back from the ganglion. action.
There can be scarcely a doubt that this is the only kind of
nervous action in those animals which have a nervous
system in its most rudimentary form—as, for instance, in
the lower mollusca. As we ascend in the animal scale, the
proportion of purely reflex actions appears to become con-
stantly smaller; but even in man those muscular actions
which minister the most directly to the vegetative life are
of this kind. The actions of the heart, lungs, and stomach Reflex
are reflex, being independent of sensation or will: the action in
heart,
stimulus to action is given in the heart by the flowing in lungs, and
of the blood; in the lungs, by the flowing in of the air; in stomach.
the stomach, by the contact of the food. And actions
which are normally performed in obedience to sensation or Reflex
will may become reflex: thus, if the spinal cord (which is actions
performed
a vast bundle of nerve-fibres, accompanied with ganglionic abnor-
mally.
cells) is so injured as to destroy all nervous connexion
between the lower extremities and the brain, the lower
extremities cease to have any sensation, or to be under the
control of the will; but the ganglionic masses of the spinal
cord act as a "reflex centre" for them; and if the centri-
petal nerves are excited, as by tickling the soles of the
feet, the spinal cord, on receiving the unfelt stimulus from
the centripetal nerves, will reflect it back along the cor-
responding centrifugal nerves in the form of a motor im-
pulse, producing convulsive motions of which the patient
is totally unconscious.

Next is what Dr. Carpenter calls consensual action: that Consen-
sual action
is to say, muscular action depending on sensation, but
involuntary; such as closing the eyes against a flash of
light, or shrinking from the contact of anything that cuts
or burns. Both reflex and consensual action are in re-
sponse to a stimulus; but reflex action, as we have seen,
is independent of any sensation, while the stimulus to
consensual action consists in sensation. Cause of
sensation
We do not know, and it is not probable that we ever unknown.

M

shall know, on what the difference depends between the
sensory and the merely reflex ganglia : in other words,
why it is that some ganglia become sentient when they are
acted on by their nerve-fibres, while others are without
that wondrous property. The microscope has not revealed
any difference between the ganglia, or between the nerve-
fibres, which are thus so unlike in their powers.

Voluntary
action :
depending
on nervous
stimulus.
Last and highest is voluntary muscular action. This,
also, as well as reflex and consensual action, in all pro-
bability depends on the stimulus of currents of nervous
energy acting on the ganglia which are in communication
with the motor nerves ; but in the case of voluntary action,
the exciting currents proceed, not, as in the other two
cases, from the outer extremities of nerve-fibres, but from
within the brain itself. I shall have to say more on this
subject when I come to treat of Mind.

It is to be observed that no line can be drawn between
consensual and voluntary action. Many actions, such as
closing the eyes or coughing, may be either the one or the
other ; and an action that was at first voluntary may
become consensual from habit ; as, for instance, the act of
walking, which, though it has to be almost consciously
learned by the child, soon comes to be carried on in re-
sponse to the sensation of touching the ground with the
feet, without needing a fresh determination of the will at
Instinct. every step. It is proved by the facts of instinct that many
actions which are voluntary in man are consensual in
many, if not all, of the lower animals. Thus, chickens pick
up grains, and ducks run to the water, the moment they
are out of the egg.

Summary. We thus enumerate four kinds of motor action in organ-
isms, according to the way in which it is produced, as
follow :—

        1st. Spontaneous.
        2d. Produced by an unfelt stimulus, or reflex.
        3d. Produced by a felt stimulus, or consensual.
        4th. Voluntary.

It is interesting to observe how these functions are suc-
cessively added, the one to the other, in the ascending

organic scale. Thus, all organisms whatever perform spon-
taneous motions : all animals, except perhaps some of the
very lowest, move in response to a stimulus : all sentient
animals move in response to sensations, and probably all
animals that have any mental power higher than mere
sensation are capable of voluntary motion.

We now come to the sensory functions. We have seen Sensory
that the nervous system is, essentially and primarily, a functions.
part of the animal apparatus for the transformation of
energy ; that it is in the highest degree probable that
every action of the nerves whatever, as well as of the
muscles, is accompanied by a transformation of energy ;
and that in sensation and thought the transformation of
vital energy is probably into heat.

I have enumerated four successive gradations of the
motor functions. The gradations of the sensory functions
are almost infinite : beginning with simple sensation, and
going on through those functions of memory, perception,
and thought, which constitute Mind. All these have their Mind.
starting-point in sensation : they consist of simple ele-
ments, which, however, form endlessly varied combinations.
In the logical order, this would be the place for a treatise
on mental science ; but I prefer to keep to the customary
order, and, so far as possible, to treat of mental science
apart, and after biology; and for the present I will
enumerate all the sensory functions under the two heads
of sensation and mind.

All the organic functions may consequently be enume- Tabular
rated in the following tabular form :—   summary.

Formative or vegetative func-tions, essentially consisting in the transformation of matter.	Chemical.	Formation of organic compounds.
	Structural.	Formation of tissue. Formation of organs.
Animal functions essentially consisting in the transforma-tion of energy.	Motor.	Spontaneous. Reflex. Consensual. Voluntary.
	Sensory.	Sensation. Mind.

M 2

I hope I have now said enough to make intelligible the statement at the beginning of this chapter, that vital functions are developed one out of the other by gradual differentiation. Formative, motor, and sensory functions are no doubt too fundamentally distinct to be produced by differentiation the one from the other.[1] But within each of these three groups there is so perfect a gradation between the various kinds, or rather the various grades, of functions, that it is easily seen how one may be developed out of the other. In the vegetative or formative series, the first and simplest functions are the chemical ones. Above these are the structural functions, the lowest and simplest of which is the formation of cells. Now cells are formed by a chemical differentiation between the constituents of the inside and the outside of the cell; so that the chemical function here passes into the structural one. And a gradation is manifestly possible from the formation of the simplest cellular tissue to that of the most complex organ. In the motor series, the gradation is decided: it is impossible to say where the one grade ends and the other begins. The same is equally true of the sensory, though perhaps less obvious: but I defer this part of my subject till I come to treat formally of Mind.

In the next chapter I shall have to state the peculiar laws of life on which the possibility of this gradation depends.

[1] See Note B (p. 166).

NOTE A.

We have seen that all organisms whatever have the power of effecting chemical transformations in matter, but the power of decomposing carbonic acid and forming the primary organic compounds belongs to vegetables alone. It is not, however, a correct account of the matter, to say that vegetables separate carbon from the inorganic world, and that the animals which eat the vegetables give it back to the inorganic world again in the carbonic acid of their respiration. The truth is that the formation of carbonic acid by respiration, which is a slow combustion, is a function of all organisms whatever,[1] and probably of every part of every organism that continues to live, (not of such tissues as nails and hair). The opposite function of decomposing carbonic acid and assimilating the carbon, on the contrary, belongs no doubt to vegetables only ; but it does not belong to every part of a vegetable, nor to every vegetable species, nor to any vegetable at all times (any air-breathing vegetable at least, for it may be different with sea-weeds, the deep-growing species of which are less dependent on light). The power of decomposing carbonic acid does not belong to germinating seeds, for they give off carbonic acid just like respiring animals. It belongs only to the green parts of plants, and to them only when exposed to light; and there are tribes of plants that have no green parts, and do not decompose carbonic acid at all, but obtain their carbon, like animals, by feeding on other plants. Such are the fungi, which obtain their carbon mostly from decaying vegetable matter ; and also the Orobanchaceæ, a tribe of flowering but leafless plants which are parasitic on other plants, and live on their juices.[2]

If then vegetables have motor actions like animals, and if there are whole tribes of vegetables which, like animals, do not decompose carbonic acid, and if the lowest classes of animals have no muscles nor nerves, what is the distinction between the kingdoms ? I reply, that I do not believe there is any absolute and certain distinction whatever.

Only vegetables decompose carbonic acid.

All organisms produce it.

Only the green parts of vegetables decompose it, and only in the light.

Vegetable tribes that do not decompose carbonic acid.

No absolute distinction between vegetables and animals.

[1] A possible exception to this is mentioned in note 2, p. 85.

[2] Carpenter's Comparative Physiology, p. 732. It is to be observed, however, that the copper beech, and other plants with leaves that are not green, decompose carbonic acid in the usual way.

NOTE B.

FORMATIVE AND MOTOR FUNCTIONS.

Actions in Foraminifera at once formative and motor.

I DO not know that it ought to be said that there is no gradation between the formative and the motor functions. The Foraminifera, and some other Rhizopods, put forth projections of the sarcode substance of the body, called pseudopodia, which are, at least as to function, temporary tentacles. May not these be truly homologous with the permanent tentacles of the Hydrozoa? If so, the putting forth and retraction of the pseudopodia, which are manifestly motor actions, are also to be classed as formative, forming the transition from the formative to the motor functions. What supports this conjecture is the fact, that in *gromia* the pseudopodia are only formed at one end, but in *amœba* they are formed on any part of the surface of the body; just as in *hydra* the tentacles all form a ring round the mouth, but in some of the compound Hydrozoa there are tentacles on various parts. Dr. Wyville Thomson appears to share this view. He says: " I am strongly inclined to regard cilia as locomotive pseudopodia, and to consider them special to the sarcode [living but structureless] element." (Embryology of the Echinodermata, *Natural History Review*, Oct. 1864.) Cilia are certainly in some degree permanent organs.

CHAPTER XV.

THE LAWS OF HABIT.

I HAVE to begin this chapter by stating in what sense I intend to use the word Habit.

We generally use the word with special reference to the Meaning mysterious border-land between the conscious and the un- of the word conscious functions. Thus we say, that such an action as habit. using some particular tool, for instance, is conscious at Conscious first, and afterwards becomes habitual. This is one of the actions becoming most important cases of the law of Habit, and for the habitual. purposes of human education it is all-important: but it is only one case of the law. Among animals in the wild state there is a great variety of instincts to which this explanation will not apply. To mention that which Uncon- Darwin justly calls "the most wonderful of all known scious instinct of instincts," we cannot suppose that the bee, in building its the bee. hexagonal cells, has, or ever had, any conscious knowledge of those geometrical properties of the hexagon which make it the most suitable form at once for convenience and for the economical use of wax. If, as I think we must, we class this and other purely unconscious instincts as cases of habit, the definition of the word habit must be greatly extended. Habitual actions, under any possible definition, include all mental and mentally determined actions which are not purely voluntary. But, if we are to extend the definition of habit so as to include under the denomination of habitual such purely unconscious instincts as that of the bee, we must include under that denomination all motor actions whatever that are characteristic either of organic species or of particular individuals. And this is

motor, and mental characteristics of every living species and individual be due to peculiarities of structure so minute and subtle as to elude the microscope ?[1]

I reply, that this would be a most plausible view if habitual characters were confined to the individuals in which they are formed. But this is not the case: all habits (that is to say, according to my definition of the word habit, all characters whatever) become, or tend to become, hereditary. This is as certain as any proposition can be which cannot be proved by experiment, but rests
for its proof on cumulative evidence. Now, we have seen that an embryo consists, not of a miniature of the parent form, but of a small mass of germinal matter, without structure or form, but having an inherited tendency to re-produce the structure, form, and all the habitual characters of its parents. This truth can be expressed in the language of the theory of habit only by saying that every habitual tendency passes, or tends to pass, from the organ which is its seat (as, for instance, the brain is the seat of mental habits) into the germinal matter of the body: and
when a portion of that germinal matter is thrown off in order to produce a new individual, it imparts its habitual tendencies to the new individual. It is, no doubt, con-ceivable that if our microscopes were powerful enough, they might reveal some peculiarity of structure corre-sponding to every habitual character of the fully formed organism. But it is not conceivable that the microscope should reveal peculiarities of structure corresponding to peculiarities of habitual tendency in the embryo, which at
its first formation has no structure whatever. I therefore conclude that in all habitual tendency there is something quite inscrutable and mysterious: as there certainly is in the tendency of the germinal matter of the embryo to develop into a new individual of its own species; which, indeed, is only a particular case of habitual tendency.

[1] This view of mental habits as depending on acquired peculiarities of nervous structure, has been lately maintained, most ingeniously and elaborately, by Professor Bain. (See the Fortnightly Review, 1st February, 1866.)

The law that all habits tend to become hereditary is subject to a very important limitation, of which I shall have to speak when I come to treat of mind.

When any peculiar tendency is inherited, it sometimes appears in the offspring at the same age at which it appeared in the parent, but sometimes earlier:[1] never, probably, or only in the rarest cases, at a later age. Hereditary diseases afford many instances of both kinds of cases : of the peculiarity reappearing in the child, in some cases at the same age at which it was acquired by the parent, and in some cases at an earlier age. A remarkable instance of the habit showing itself at an earlier age, is the fact of young dogs, the parents of which have been taught to point, themselves sometimes beginning to point the first time they are taken out.[2] I agree with Darwin in attaching great importance to this class of facts, respecting the age at which variations occur, in throwing light on the origin of species.

There can be no doubt that even when a habit does not become hereditary, a tendency to it, or a facility for acquiring it, does become hereditary. In those cases, for instance, in which a young pointer has not inherited the habit of pointing, that habit is nevertheless more easily acquired by him than it would be by a dog whose ancestors had not been taught to point. The case of a dog

Inherited characters appear sometimes at the same age as in the parent, sometimes earlier.

Hereditary tendency without special habit.

---

[1] Darwin on the Origin of Species, 4th ed. p. 14. (It is from the fourth edition I shall always quote.)

[2] The following is a very striking instance of the same kind : "Sir C. Lyell mentions that some Englishmen, engaged in conducting the operations of the Real del Monte Company in Mexico, carried out with them some greyhounds of the best breed to hunt the hares which abound in that country. It was found that the greyhounds could not support the fatigues of a long chase in this attenuated atmosphere, and before they could come up with their prey they lay down gasping for breath ; but these same animals have produced whelps, which have grown up, and are not in the least degree incommoded by the want of density in the air, but run down the hares with as much ease as do the fleetest of their race in this country." (Carpenter's Comparative Physiology, p. 987.) In this case the power of breathing with facility in a rare atmosphere, which only had a tendency to be produced in the parents, was congenital in the offspring.

which is easily taught to point because his ancestors have been taught before him, is similar to that of a man who once learned to practise an art or to speak a language, and, though he has forgotten it, can learn it again much more easily than he could if he had never known it. The fact of the dog's ancestors having learned to point gives the same facility to the dog himself in learning it, which the fact of the man having once learned an art gives him in learning it again.[1]

Habit is changeable,

Another most important law of habit must be formally stated, though it is implied in what has been said about the acquisition of new habits. It is, that all habits are in some degree changeable. New habits are constantly produced by change of circumstances, and by education, which indeed is only a special and artificial set of circumstances: and this could not be the case if habits were not in some degree changeable.

and spontaneously variable.

But besides the *changeability* of habit as the result of changing circumstances, there is a certain amount of *spontaneous variability*, which does not depend—at least not directly—on change of circumstances. No child is exactly like either of its parents, and no two children of the same parents are exactly alike. These differences might be attributed to differences of circumstances acting on the offspring through the parents; but such an explanation is shown to be at least insufficient, by the fact that the same differences are found to exist between twins, though, in general, in a somewhat less degree than between other children of the same parents; and it is obvious that twins have been subjected to precisely the same influences. The same is very generally true of those domesticated races of animals which produce several young at a birth.

It is a most important, and a much debated question, whether there is any limit to spontaneous variation. Variation in a single generation is beyond doubt confined within very narrow limits: no such variations appear to be possible (among the higher animals and vegetables at least) as would be implied in " gathering grapes of thorns

[1] See Bain on the Emotions and the Will, Appendix C.

and figs of thistles." But I agree with Darwin in be- I believe
lieving that there is no limit to the possible extent of in no limit
to varia-
variation acting cumulatively, if only a sufficient number tion.
of generations is allowed;—no limit, I mean, as to the
possible *extent* of change: there are, I believe, definite laws
as to its *direction.* Of these laws we know but little; it
is, however, a very important truth, that variation does not
go on equally in all directions at once, but takes place in
particular directions at particular times: in other words,
organisms acquire *habits of varying* in particular direc- Habits of
tions; and these habits of varying are characteristic not varying.
only of individuals but of species and genera; perhaps
we may say, of whole classes. As an instance of this—
not by any means the strongest instance I can think of,
but the most familiar—may be mentioned the well-known
fact that the acquisition of any power that depends on
habit makes it easier to acquire other powers of the same
kind: thus, the mastering of one language makes it easier Instance
to master other languages. This is not simply a case of a of acquir-
ing lan-
habit perpetuating itself. The knowledge of any language guages.
consists in the habitual connexion in the mind between
the words of the language and the ideas they represent, so
that the one will recall the other without effort; and these
connexions are different for every different language. But
though the habitual connexions are different, the habit
which is cultivated in acquiring them for one language
facilitates their acquisition for another: a habit has been
acquired of acquiring a particular kind of habits. This
law, that organisms acquire a habit of varying, or, in other
words, of altering their habits in particular directions, is
shown by Darwin to be true of the formative functions as
well as of the motor and mental ones; and he has clearly
perceived its great importance in accounting for the origin
of species. I shall have more to say on this subject in a
future chapter.

Habits, as we have seen, are formed and strengthened
by repetition of the acts. This, indeed, is only a state-
ment of the elementary law of habit. The converse is Habits are
also true: habits are weakened, and may at last be weakened

and de-
stroyed by
disuse.

Strength
of a habit
depends
on time
during
which it
has been
exercised,
and on
time since
it has been
exercised.

Present
strength
of a habit.

Tenacity
of a habit.

destroyed, by discontinuance of the acts ; as, for instance, when we forget how to speak a language, or to practise an art, which we once knew but have discontinued. From these two laws—that habits are strengthened by repetition of the acts, and are weakened by their discontinuance—it follows that the strength of any particular habit, other things being equal, depends on two different factors : one, the length of time during which the habit has been exercised ; the other, the shorter or longer time that has elapsed since it has been exercised. The effect of these two factors, however, is not the same in kind. The *present strength* of any particular habit depends chiefly on its having been recently exercised ; but the *tenacity* of a habit, or, in other words, the difficulty of weakening or destroying it by disuse, is a different thing from its present strength, and the two do not stand in any constant proportion to each other. The tenacity of a habit depends on the length of time during which it has been exercised : that is to say, the longer a habit has been in forming and strengthening by exercise, the longer time it will take for it to be weakened or destroyed by disuse. These facts are familiar. Every one knows that habits of long standing are not easily lost ; and the most tenacious habits are those which belong to the species, and have been exercised not merely through a lifetime but through an unknown number of generations.[1] Hereditary characters, indeed, are seldom —I believe never—destroyed by disuse during a single generation, though they may be destroyed by disuse during many generations : the domestic fowl and duck, for instance, have nearly lost the power of flight by long-continued disuse. Thus the law of the hereditary transmission of habit is equally true of its destruction as of its formation.

Hereditary
characters
are the
most
tenacious.

[1] I am surprised that Darwin should say, " I do not wish to dispute the truth of the proposition that inheritance gains strength simply through long continuance, but I doubt whether it can be proved." (Variation under Domestication, vol. ii. p. 26.) That inheritance should so gain strength appears to me at once a necessary consequence of the laws of habit, and a necessary inference from the general truth that the characters of the variety are more variable than those of the species.

For the sake of clearness, I have stated the law of the Weaken-
weakening and destruction of habits by disuse as if it ing of habits by
were an independent law.   But in reality it is not so : disuse is a
it is a mere case of the elementary law of habit.   The case of the general
elementary law is, that by acting in any way a habit is law.
formed of acting in that way : and it is a mere case of that
law, that by ceasing so to act, a habit is formed of not so
acting; or, what is the same thing in other words, the All actions
habit of so acting is lost.   The only really elementary become habitual :
laws of habit are these three : that all actions, whether all habits
formative, motor, or mental, tend to become habitual; that become hereditary:
all habits tend to become hereditary; and that all habits all habits are vari-
are in some degree variable. able.

As I have stated, the present strength, or what may be
called the *prominence* of a habit, depends on its having
been *recently* exercised; but its *tenacity* depends on what
is quite different, namely, the *length of time* (millions of
generations, it may be) during which it has been exercised.
These simple and well-known truths are little more than
obvious corollaries from the elementary laws of habit; but
on them depend some very remarkable and rather intricate
interactions between different habitual characteristics.   A
habit which has been much exercised during a compara-
tively short time may be very prominent, but it cannot be
very tenacious; and it may be lost by disuse during a
period of time which is too short to produce any per-
ceptible effect in destroying a more tenacious, though
perhaps less prominent habit.   Cases of this kind are no
doubt difficult to identify, but it certainly is possible that
new mental and moral habits, amounting to a change of
character, may be acquired as a result of education and
circumstances, and may afterwards disappear with ad-
vancing age and under new circumstances, while the Reappear-
original, perhaps hereditary, character reappears. ance of old habits.

A tenacious habit may appear to be lost when it is in Latent
reality only latent.   A latent habit is one which, though habits.
not obvious, may at any time reappear; sometimes spon-
taneously, sometimes by placing the organism in the same
circumstances as those which produced the habit at first.

It is a well-known instance of this, that when the use of an art, or of a language, has been laid aside so long that, at the first attempt to recommence it, it appears to be totally lost, a little practice will often prove sufficient to regain it in a mere fraction of the time that would be necessary to learn it if it were really new. This is a case of the rapid reappearance of a latent habit under favouring circumstances. The most remarkable instance of the spontaneous

Reversion to ancestral characters.

reappearance of a habit is the reversion of individuals, and, as I believe, of species, to ancestral characters after the lapse of many generations; which, according to general belief, sometimes occurs in the human race, and beyond all question does occur among domesticated breeds of animals.[1] The characters of the breed which have arisen under domestication, and consequently are of later date than those of the species, are *prominent* habits: those of the species which reappear in these cases of reversion are *tenacious* habits, which may, as it were, be overlaid and concealed by the later acquired ones for a great number of generations, and yet reappear at last. I shall have to speak, further on, of the importance of this class of facts in accounting for the characters of species.

In the chapter on the Dynamics of Life I have stated my belief that the differentia of life consists in certain powers, which all living beings possess, of transforming matter

Laws of habit are elementary and universal laws of life.

and energy. Except the laws of those transformations, I believe the elementary laws of habit are the only laws of life which are at once elementary and universal. I regard these as ultimate laws, like the laws of gravitation and of the affinities of the chemical elements, and, like them, incapable of being referred to any others.

Active habits strengthen, passive impressions weaken, by repetition.

It is an important result of the laws of habit, that while active habits are strengthened by the repetition of the act, passive impressions are weakened by the repetition of the impression.[2] Both of these facts are perfectly familiar:

[1] Darwin's Origin of Species, pp. 15, 190. The most remarkable instances, both of variation and of reversion, are those of the domestic pigeon.

[2] So far as I am aware, this remark was first made in Butler's " Analogy of Religion."

every one knows that being habituated, or accustomed, is
an explanation alike of being able to do what an unaccus-
tomed person could not do—as, for instance, to execute
a difficult piece of music ; and of being able to resist what
an unaccustomed person would have great difficulty in
resisting, such as great heat or cold, and impressions of par-
ticular kinds of horror or fear. These effects are opposite,
and it might appear that the weakening of impressions by
repetition is the result of a distinct law, opposite in its
character to the general law of habit ; but it is in reality a Both are
case of that law. A passive impression becomes weaker by cases of
one law.
repetition, because the organism acquires the habit of not
responding to it. A passive impression means one which
is not followed by action. An impression which is not
followed by action differs from one which is followed by
action, not in the nature of the impression, but only in the
response the organism makes to it. The same impression,
acting on two similar organisms, may, according to circum-
stances, remain a merely passive impression on the one,
and may become an active stimulus to the other. To
mention a familiar instance : two men hear the same loud Instance
bell in the morning ; the one is accustomed to awake and of the
effect of an
get up at the sound, and he awakes ; the other is accus- accus-
tomed to disregard it, and he disregards it and sleeps sound.
through it.[1] This view is supported by the fact, that it is
possible to increase the strength of merely passive feelings
—feelings, that is, which do not lead, and are not meant to
lead, to action—by the habit of brooding over them ; and,
without so much mental action as is implied in brooding,
it is possible to give a mastery over the mind to the passive
emotions, especially to fear, merely by acquiring a habit of
yielding to it.[2]

All this is familiar ; but, so far as I know, it has not yet
been clearly pointed out that the law of passive impressions
weakening by repetition, while active habits strengthen

---

[1] I have met with this illustration of the law somewhere in Whately's
writings.

[2] See Bishop Fitzgerald's Note B to Chap. V. of Butler's "Analogy of
Religion."

N

The same is true of the uncon- scious life. from the same cause, is not confined to mental and volun- tary actions, but has its foundation far down in the uncon- scious life. One instance of this is the well-known fact,

Effect of medicines and stimu- lants. that the power of medicines and stimulants is diminished by constant use. Another and very remarkable instance of the law is the way in which the heart responds to a

Action of the heart under a stimulus. stimulus; such as a blow, or a sudden fright, or an electric shock. The first effect of a stimulus on the heart is to cause a momentary cessation, or at least slackening, of its action. If the shock is violent enough, it causes death; but otherwise the effect passes away, and is followed by a quickening of the heart's action—the well-known " beating of the heart" produced by a shock. If the stimulus is repeated, supposing its intensity to be the same, its effect will become less with every repetition,[1] showing that the heart is acquiring the habit of not making any response to it—just like the sleeper who acquires the habit of making no response to the bell. From such instances as these—

General law re- specting passive im- pressions. which are clearly not exceptional, but normal—I think we may infer, not only that, as already stated, organisms are capable of acquiring a habit of not responding to stimuli, but also that they always do form such a habit, unless there is some cause to determine them to form the opposite habit; namely, the habit of making a response. A still more remarkable instance of this law, and one where neither voluntary determination nor nervous action of any kind can come into play, is afforded by the motions of

Instance of climbing plants. those climbing plants which have been already referred to. It is stated by Mr. Darwin, that a thread weighing no more than the 32d of a grain, if placed on a tendril of the *Passiflora gracilis*, will cause it to bend; and merely to

---

[1] Claude Bernard, in *Revue des Deux Mondes*, March 1, 1865. The stimulus used in such experiments is that of an electric current sent through the pneumogastric nerve. The heart, in relaxing under a stimu- lus, acts differently from other muscles, which contract under the same; the arteries, which have a muscular coat, contract under a stimulus, such as drawing the point of a needle over the skin without making a scratch ; but though this effect is opposite in kind to that produced by a stimulus on the heart, yet, like the latter, it is weakened by repetition. (Carpenter's Human Physiology, p. 231.)

touch the tendril with a twig causes it to bend ; but if the
twig is at once removed, the tendril soon straightens itself.
But the contact of other tendrils of the plant, or the falling
of drops of rain, do not produce these effects—proving,
apparently, that the tendrils have acquired the habit of
disregarding these :[1] a wonderful instance of vegetable
instinct.

It is a most important fact that organs increase with
exercise, not only in functional power, but also in size ;
while, conversely, organs that are disused, in whole or in
part, diminish, not only in functional power, but also in
size : and such modifications, like all others, are capable of
becoming hereditary.   It is difficult to prove that this con-
nexion between the habitual exercise of an organ and its
magnitude is true of the organs of the nutritive life, because
most of them are incapable of any excessive stimulation
without producing disease ; but I think the " expansion of
the chest " which properly-directed exercise produces, shows
it to be true of the lungs.   It is well known to be true of
the muscles ; and though the evidence is less direct, I
think it is scarcely possible to doubt that it is so of the
organs belonging to the nervous system—that the brain,
for instance, is increased in functional power and in size by
successive generations of mental cultivation.[2]

It will be noticed by the reader that I have taken the
instances of habit which I have quoted, indifferently from
among mental and bodily habits, or, as I prefer to say,
from among conscious and unconscious habits ; showing
how the same laws of habit govern both the conscious and
the unconscious life.

It is to be observed that the laws of habit do not account
for the origin of every particular habit.   This, however, is
not because of any imperfection in our knowledge of the
subject : it is because the laws of habit, by the definition
of the word, have to do only with the repetition of actions
and the perpetuation of tendencies ; but they do not neces-
sarily throw any light on the cause of the first of a series

Marginal notes: Organs grow with exercise. Lungs, muscles, and brain. Laws of habit are true of both mind and body. Laws of habit do not account for every particular habit.

[1] Quarterly Journal of Science, April 1866.
[2] See Note at end of this chapter.

N 2

of actions that has become habitual—just as the laws of
motion, though they are perfectly well understood, throw

Voluntary
actions
may
become
habitual. no light on the origin of force. We know that in man,
and in a less degree among the more intelligent animals, a
great variety of actions are capable of becoming habitual
that were voluntary in their origin. On this possibility

This will
not ac-
count for
all habits. the whole art of education is founded. But this explana-
tion will evidently not apply to the facts of what I have
called spontaneous variation; nor will it apply to any
formative habit whatever, nor to such motor habits as the
cell-building instinct of the bee, or the turning and twining
instinct of the *Passiflora gracilis*, mentioned above. By
the definition of habit that I have adopted, all specific
characters are habits; and, in this sense, the question of
the origin of particular habits includes the whole vast and

Question
of the
origin of
species. enigmatic subject of the origin of species. · But, little as
that subject is understood, recent research and speculation
have let a few rays of light into the darkness.

Summary. We may thus sum up the laws of habit :—

Habit. All vital actions—formative, motor, and mental—tend
to become habitual.

Heredi-
tary trans-
mission. All characters tend to become hereditary. An acquired
character, when transmitted to offspring, appears some-
times at the same age at which it appeared in the parent,
sometimes earlier.

Variation. All characters are in some degree variable, and particular
characters may acquire a habit of varying.

The foregoing three are the *elementary* laws of habit;
the following are derived as corollaries from them :—

Disuse. Habits, being formed by use, are weakened and destroyed
by disuse.

Promi-
nence. The *prominence* of a habit, or its present strength, depends
on its having been *recently* exercised.

Tenacity. The *tenacity* of a habit, or the difficulty of destroying it,
depends on its having been *long* exercised.

Consequently, a prominent habit may disappear, while a
tenacious, perhaps a hereditary one, survives it.

A habit may become latent, and reappear. The re-

appearance of habits is sometimes the result of favour-
ing circumstances, sometimes spontaneous. Reversion to *Reversion.*
ancestral characters is a case of the reappearance of habits. ·

When a stimulus is responded to, it strengthens in force *Passive impres-*
with repetition ; when it is not responded to, it weakens. *sions.*

Organs strengthen and enlarge with exercise ; and, con- *Effect of habit on*
versely, they weaken and diminish with disuse. *organs.*

It is now time to consider, in more detail than I have
yet done, the manner in which the characters of a race
will be modified by changes in the circumstances under
which it has to live.

It is a universal law, that the health, and ultimately the *Great changes*
life, of any organism whatever will be destroyed by any *are de-*
very great change in external circumstances. The most *structive.*
obvious instances of this law are the familiar facts, that
air-breathing animals will die in the water, and water-
breathing ones will die in the air. These facts, however,
do not throw much light on any law of life, for they admit
of a purely physical explanation. It is physically impos-
sible, quite irrespective of any law of life, that a man's
lungs should breathe water, or that a fish's gills should
breathe air. But, independently of physical reasons like
this, all great changes are destructive of health and life.
Cold regions and warm ones, moist places and dry ones,
have all their own peculiar races of animal and vegetable
inhabitants ; and those species which are native to one
kind of abode will, as a general rule, be destroyed by
transplanting to a totally different one. Were it not so,
differences of climate would be no barrier to the migrations
of species, instead of being, as they often are, the most
impassable of all barriers. In many cases we cannot say
what is the reason of this inability of organisms to adapt
themselves to new circumstances. Sometimes, in all pro-
bability, it is in part merely physical : for instance, animals
with a coat only of hair may be unable to endure the cold
of those countries where most of the native quadrupeds
are clothed with fur. But this kind of reason cannot be
given in every case. It is, I think, quite impossible to

This is not always physically explicable. assign any such merely physical reason for the fact that the European race of man is unable to perpetuate itself in the climate of Bengal. I believe such facts are to be referred to the laws of habit. We have seen that every organism has a certain power of becoming habituated to impressions. This it does in two different ways: if the impression demands a response, such as to close on its prey or to run away from its enemy, the organism acquires the habit of making the right response; if it does not demand nor admit of any response, the organism acquires the habit of disregarding it. Now, exposure to a different climate from that to which an organism has been accustomed, in some cases, no doubt, produces a response in the vegetative life—as, for instance, in those animals which acquire a coat of hair better suited to their new abode; and sometimes it produces a response in the motor life, as when it determines a species to acquire the habit of periodical migration. But in many cases—probably in the vast majority—no appropriate response is possible. To use familiar language, nothing can be *done*, and the change—the unaccustomed heat or cold—must be *endured*. The organism must become habituated to the climate—that is to say, must acquire the habit of disregarding the change; Organisms are destroyed by changes that they cannot become habituated to. and if it cannot do this, the change will destroy its health, and ultimately its life. It may not be sufficient to kill the individual; but if its health is at all injured, and this is not recovered in future generations, the race will die out of its new abode. This kind of adaptability is very different in different species: thus the horse has been successfully introduced by man into every climate, from the equator to Iceland and Siberia: the ass would perish in a very cold climate.

Great and sudden changes of circumstances are destructive. The reasoning in the foregoing paragraph may seem vague. I am, however, convinced that there must be some profound connexion between the two facts, that great and sudden changes in the circumstances of their lives are destructive to organisms, and that organisms are unable to effect great changes in their habits, except very gradually. The proof that there is such a connexion

is strengthened by the converse facts which I have next
to state.

As just stated, great and sudden changes of circum- Corre-
stances are destructive, and great and sudden changes of sponding
changes in
habits are impossible.   I believe we might say that great habit are
impossible.
and sudden changes of circumstances are destructive,
because great and sudden changes of habits are impossible.[1]
And what confirms the belief that these two laws really
stand in the mutual relation of cause and effect is this
further pair of laws, which evidently are similarly related
to each other,—that great changes of circumstances are Great
often not destructive, provided they are not sudden; and changes if
not sudden
that great changes of habit are often possible, provided are often
not de-
they are not sudden.   I believe we may say, as before, that structive.
great and gradual changes of circumstances often are not Corre-
sponding
destructive, *because* great and gradual changes of habit are changes in
possible.   I do not yet wish to speak of those changes which, habit are
possible.
as I believe, have occurred in geological time; but, as an
instance of a wonderful change that has occurred in histo-
rical time, I may mention the dog, which, though naturally
carnivorous, has in his domestic state gradually become in
great part a vegetable feeder, and has been taught to tend
sheep.   These changes must have taken many generations
to bring about.   A carnivorous animal would perish if sud-
denly put on a vegetable diet: not that it would disagree
with him—he would die of hunger sooner than touch it.

The process of adaptation—or, in other words, the effects Adapta-
tion, how
of changes of circumstances in producing new habitual cha- effected.
racteristics—may now be stated; not, indeed, in detail, but
with some degree of precision.   External changes, if of any
importance, will either destroy the organism, or cause the
organism to acquire new habits, so as to adapt itself to the
changes.   The new habits will be either active or passive. Active and
passive
An animal may, for instance, be placed in a severer climate habits.
than that to which it is native: this may take place either

---

[1] Herbert Spencer would probably say, that if the organism, or the race
of organisms, is unable to readjust its internal relations to the new set of
external relations, it will perish.   This would no doubt be true, but I do
not see that it would be in any sense an explanation.

Change o.
climate.

from such a change of climate as we know from geological
evidence to have taken place in past ages,[1] or from the
animal being transported by man and becoming wild in
its new abode, or from spontaneous migration; and it is
sometimes impossible to say what determines the migra-
tions of animals. In such a case, as already remarked, the
animal, if it becomes adapted to the new climate at all, and
is not destroyed by it, may become adapted by acquiring
either the passive habit of disregarding the cold, or the
active habit of producing warm fur on its skin. Of passive
habits I need say no more; but the subject of the forma-
tion of active habits, including formative ones, to meet
new circumstances of life, is practically an infinite one.
Suppose another instance of the same kind. In conse-

Change of
food.

quence of the migrations of the animals that serve as its
food, a beast or bird of prey is compelled to change its
mode of hunting.[2] It may need keener sight, in order to
obtain its new prey: in this case, its sight will be more
exercised, and will become stronger; and in the course of
some generations, probably, its eyes will be enlarged. Or
it may need a keener sense of smell: in this case the same
changes will be effected in its olfactory organs. Or it may
need greater fleetness: in that case the muscles of its legs
will become stronger and larger; and, what is most im-
portant to observe, such a change as this will directly or
indirectly affect the form of every part of the body—partly

---

[1] I do not mean that there is any proof of a glacial period being one
of extreme cold. A *cold summer* would be enough to produce it.

[2] Migrations sometimes occur in very unexpected ways. I extract the
following from the Quarterly Journal of Science, October 1864 :—

"The sudden occurrence of Pallas's sand-grouse (*Syrrhaptes paradoxus*)
over the greater part of Europe has attracted the attention of ornitholo-
gists, and Mr. Alfred Newton has collected information which shows that
this remarkable bird, hitherto almost unknown to the European fauna,
has been met with during the year 1863 in no less than 148 localities in
Europe and Great Britain, tracing the invading host through 33° of longi-
tude, from Galicia to Donegal. He regards the proximate cause of this
wonderful movement as the natural overflow of the population of *Syrrhaptes*,
resulting from its ordinary increase, being a bird which has comparatively
few enemies, while its time of incubation is short in comparison with what
it is in most ground-feeding birds."

The *Syrrhaptes* is a native of the steppes of Central Asia.

by the direct action of the pressure of the enlarged muscles, modifying the form and position of the other muscles and of the bones—partly also, no doubt, by the increased nutrition demanded by the enlarged muscles diminishing the supply of nutrition to the other parts of the body, and so compelling a diminution of their size. It is also to be observed that, besides these secondary changes, as they may be called, it is quite possible for change of habit, as the result of new circumstances, to take place primarily in two or more directions at once. Thus, for instance, the necessity of pursuing a new kind of prey, or of pursuing the same kind of prey in a different manner, as will occur when forests are destroyed, may have the effect of causing an animal to improve both in keenness of sight and in fleetness. This appears to be not only a possible, but a probable case: keenness of sight and fleetness are often united in animals, as, for example, in birds of prey. *Improvement in sight and fleetness.*

In this chapter I have considered the laws of the formation and perpetuation of habit; in the next I shall have to consider the laws of its variation.

NOTE.

GROWTH OF ORGANS WITH EXERCISE.

IT appears uncertain whether the increase in size of organs that are much exercised can be accounted for by any physical cause ; or whether, like the law of habit, it is an ultimate law of life, and as such inexplicable. Herbert Spencer has made a most elaborate and ingenious attempt to prove that it is entirely due to the increased flow of blood that always takes place to and through an organ in activity.[1] He makes out an exceedingly strong argument for believing that the deposit of woody substance in the vascular tissue of plants, which is the process by which woody fibre appears to be formed, is originally due to the accelerated flow of the sap in the vessels near the surface of *Why do organs grow with exercise? Herbert Spencer's theory.* *Woody fibre.*

[1] Principles of Biology, Part V. Chaps. iv., vii., and viii.

trunks and branches that are agitated by the wind. But it ought not to be taken for granted that the case of muscular and other animal tissue is parallel to this. In plants, the waste of the tissues is very trifling, and it is probably null in vascular tissue which is filling up and hardening into woody fibre; so that an increased flow of sap may very well fill up the vessels with the substance it brings, just as drains are silted up. But

Animal tissues.

in animals, especially warm-blooded animals, the waste is great and rapid; and the more any organ is exercised, the more substance it loses by waste: and it is not easy to understand why the increased flow of blood through an organ should not only increase its nutrition (which it certainly will do), but cause the

Possible nervous action in increasing nutrition in exercised parts.

nutrition to exceed the waste, so as to produce growth. Perhaps the excess of nutrition to which the growth is due may be in some way caused by nervous agency, which we know to be called into play by every vital action whatever among those classes of animals that have a well-developed nervous system. Such action of the nervous system would, no doubt, be inexplicable; but it would not be more so than its action in stimulating secretion,[1] or, indeed, than any strictly vital action whatever.

Increased flow of blood to exercised parts,

The cause of the increased flow of blood to and through parts that are in exercise does not appear to be fully understood. With respect to the muscles, I am inclined to think that Herbert Spencer has assigned an adequate cause, namely, the varying pressure on the blood-vessels during muscular action. But this, obviously, will not apply to the flow of blood to the brain being greater during the waking state than during sleep, or any other

possibly due to relaxation of the nerves of the arteries.

flow that is directly produced by nervous action. Possibly the increased flow of blood in this class of cases may be due to the calibre of the small arteries being increased by the relaxation of the nerves that control them; but I only offer this as a suggestion.

[1] Carpenter's Human Physiology, p. 738.

CHAPTER XVI.

THE LAWS OF VARIATION.

IN the last chapter we have seen that the habitual Changes of habit, function-ally pro-duced, and spon-taneous. characters of organisms are subject to two quite distinct classes of changes, which, following Herbert Spencer, I shall call *functionally produced changes* and *spontaneous variations.* I shall have to speak, farther on, of a kind of changes concerning which it is difficult to say how they are to be classed. I have to some extent, though in extreme outline, traced in the last chapter the laws according to which changes are functionally produced, and I now go on to state the conditions which are favourable to variation. I must, however, begin by stating a set of laws that have no very obvious connexion with the subject.

We have seen that great and sudden changes of habit are impossible, and that great and sudden changes of external circumstances are destructive to an organism. Whatever may be the connexion of these two laws with each other (and I believe it is very close), their opposites are also true: slight changes of habit are possible, and Benefit of slight changes. slight changes of external circumstances are beneficial to organisms. Concerning the variability of habit, I need not say anything more at present; but, as an instance of the beneficial effect of slight changes of external circumstances, may be mentioned the proverbial benefit of " change of air " Change of air. —that is to say, in reality, change of external circumstances —in renewing the bodily and mental health, especially of sufferers from monotonous, depressing, or exhausting occupation ; and the equally well-known benefit of " changing Change of seed. the seed " of cultivated plants—that is to say, bringing the

seed from a distance, instead of sowing that which has
been raised in the same farm or garden.

Benefit
of slight
mixtures
of race.

I agree with Darwin [1] in believing that there is a pro-
found connexion between this last-mentioned law and the
general law, that slight mixtures of race, or " crossings of
the breed," tends to promote the health and vigour of the
race.   I say *slight* mixtures, because very different races
will not mix at all: the pollen of a rose on the stigma of a
foxglove, for instance, would produce no more effect than
if it were so much dust blown off the road.   And between

Mixtures
of unlike
races.

these two extremes of kindred races which are benefited
by mixture, and totally distinct races which will not mix
at all, there is a wide class of intermediate cases.   Some-
times, when two distinct species of plants are hybridised,
seed is produced, but in less abundance than if the plant
bearing it had been fertilized with pollen of its own species.
Sometimes, among animals, the offspring is vigorous, but
infertile, and cannot give origin to a hybrid race: the
mule, between the horse and the ass, is a well-known
instance of this.   Sometimes offspring is produced, but is
weak, and dies early ; sometimes, in the case of birds,
without being able to break through the egg.[2]

Slight
changes are
agreeable,
great ones
disagree-
able.

There is another set of facts which I will mention here,
though they are not relevant to the subject of the present
chapter, because I believe they stand in the closest con-
nexion with the laws of habit and of the effects of changing
circumstances.   I mean that, among conscious organisms,
slight changes are agreeable, but great changes painful, or
at least disagreeable.   This law is a most important one in
mental science.

Summary.

I have now enumerated four pairs of laws which, it is
scarcely possible to doubt, stand in the closest relation to
each other.   They are as follow :—

[1] Origin of Species, p. 318.
[2] Ibid. p. 315.   See the whole chapter on Hybridism.   Darwin says,
that the impossibility of obtaining hybrid offspring at all in some cases,
and the infertility of such offspring in other cases, are very distinct facts :
but I think it needs no proof that they are facts of the same class.   In
the former, we cannot obtain hybrid individuals : in the latter, we cannot
obtain a hybrid race.

Habits are capable of change; but only a slight change is possible in a short time.

Changes of external circumstances are beneficial to organisms, if they are slight; but injurious if they are great, unless made gradually.

Changes of external. circumstances are agreeable to the mind when slight, but disagreeable when great.

Mixture of different races is beneficial to the vigour of the offspring, if the races mixed are but slightly different; but very different races will produce either weak offspring, or infertile offspring, or none at all.

It is a very remarkable fact, that confinement to a small area appears to have a tendency to diminish the size of a race of animals, even when there is no other evidence of diminished health and vigour. Thus, animals found on islands are frequently smaller than those of the same species found on continents; and animals bred in an aquarium are often observed to degenerate in size, even while the race continues vigorous.[1]   It is scarcely possible to doubt that such diminution is caused by want of room for sufficient variety in the conditions of life, or by want of sufficient mixture of the race—in other words, by the interbreeding of too small a number of individuals—or most probably by both; though the second reason will not apply in cases where the diminution is visible in a few generations among species of organisms that are able to propagate for a long time without union of the sexes.[2]

Effect of confinement to a small area.

What may be called the law of sexuality in organisms— that is to say, the necessity of the union of two unlike individuals of the same species for the purpose of genera-

Sexuality.

---

[1] I state these facts on the authority of Mr. (now Sir John) Lubbock's paper on the reproduction of Daphnia. (Philosophical Transactions, 1857.) The Daphnia is a small fresh-water entomostracous crustacean.

[2] Ability to propagate without union of the sexes is not the same thing with hermaphroditism. The land mollusca (snails and slugs) have both the sexes on the same individual, and yet they cannot fertilize themselves. On the other hand, no winged insect is a hermaphrodite, and yet many species produce fertile eggs without impregnation.

tion—appears to stand in the closest connexion with the
law of the beneficial effect of slight mixtures of race :
indeed, the former law is probably only a case of the
latter.   This connexion, and the whole subject of the real
nature of generation, can be made manifest only by study-
ing it among the simplest and lowest organisms.

When the generative process is studied only among the
highest organisms, among which it is always sexual, the
inference is natural and inevitable that generation is
altogether a special function; but its phenomena among
the lowest organisms show that it is only a modification of
the general vital process of growth and development.   I
will here briefly recapitulate what I have said on its true
nature in the chapter on Organic Development.   Any por-
tion of the structureless germinal matter of any organic
species is capable of developing into a perfect individual
of the species, when placed under suitable circumstances;
but the higher the organization, the more special the cir-
cumstances are required to be in order that it may so
develop.   In *hydra*, a form in which there is little dis-
tinction between germinal matter and formed material, a
single small fragment, if detached, and permited to remain
in any place where a perfect *hydra* can live, will soon
develop into a perfect *hydra*.   In the vast class of the
Protozoa, which are the simplest of all animals, and among
vegetable tribes of equal simplicity, propagation very gene-
rally takes place by means of spontaneous division into
parts.   But among the higher forms, in which the life is
more centralized, and the parts more mutually dependent,
a portion of germinal matter, if simply detached, will not
develop into a new organism, but will die; and, conse-
quently, special generative organs are set apart, in which
the germinal matter is prepared and supplied with nourish-
ment in a particular form, for the purpose of its developing
into a new organism.   Among the lowest organic forms,
reproduction can scarcely be distinguished from growth.
Among all Algæ—and, indeed, throughout the vegetable
and animal kingdoms—cells give birth to cells.   Among
the lowest Algæ, in which each individual consists of but

Marginal notes:

Genera-
tion is
only a
modifica-
tion of the
general
vital
process.

Reproduc-
tion of
Algæ.

a single cell, cells divide into cells; and when they have
divided, they separate. Among forms a little higher, they
adhere together after dividing, and constitute cellular tissue.
When they separate, we call the result propagation; when
they adhere, we call it growth: but there is evidently no
fundamental difference between the two cases; they are
found in nearly allied forms, and, indeed, they graduate
into each other through species in which the adhesion of
the cells is very slight.[1]

The reproduction just described is non-sexual; but the Simplest
first and simplest form of sexual reproduction is presented form of
sexual
by those same unicellular Algæ. There is no distinction reproduc-
of sex, but reproduction takes place by means of the fusion tion in
unicellular
into one mass of the germinal matter that forms the con- Algæ.
tents of two cells. Among the Diatomaceæ and Desmideæ,
two individuals, each of them consisting of but a single
cell, place themselves together and burst: the contents of
the two mix, and from their union a fresh brood arises.[2]
Although there is here no visible distinction of sex, yet Its essen-
what appears to be the essential condition of sexual repro- tial con-
dition is
duction is fulfilled; namely, the fusion of the germinal mixture of
matter derived from two different organisms, or, at least, germinal
matter
two different cells. In the case just described, the cell- from two
sources.
walls, after they burst and liberate their contents, are as
useless and dead as the cast skin of a snake. But in the
zygnema—an Alga of rather higher organization, which Zygne-
consists of cells united into filaments, somewhat like strung ma: sim-
plest form
beads—we meet with the first and simplest form of the of sexual
distinction between the sexes. Two of the filaments—that distinc-
tion.
is to say, two distinct plants—approach and lay themselves
alongside each other, and the contents of the cells of one
filament pass over into the cells of the other, where the
union is formed which is to give origin to a new brood.[3]
The essential matter in sexual generation is the union of Purpose
germinal matter from two distinct sources; and the pri- of sexual
distinc-
mary purpose of the distinction between the sexes appears tion, to in-
to be to increase this difference. It would be premature crease the
difference

---

[1] Spencer's Principles of Biology, vol. ii. pp. 15, 16.
[2] Carpenter's Comparative Physiology, p. 878.   [3] Ibid. p. 881.

of the two
sources.

to say that this last statement is proved; but it certainly receives strong confirmation from the facts that Darwin has collected, and on which he justly lays great stress, concerning the fertilization of hermaphrodite organisms.

Herma-
phrodite
animals,

Many of these, as land-mollusca and earth-worms, have the male and the female organs so placed with respect to each other, that they cannot fertilize themselves, but pair, like animals with the sexes on distinct individuals. And though many hermaphrodite animals do habitually fertilize themselves, yet Darwin states, on Huxley's authority as well as his own, that among known animals there is not a single instance of the female organs being out of the reach of the spermatozoa of another individual occasionally entering. No terrestrial animal is known to fertilize itself, and among aquatic species the spermatozoa may be

and plants,
not always
self-ferti-
lizing.

carried in currents of water.[1] With respect to plants, the evidence is even more remarkable and more decided. Most flowers are hermaphrodites; and when the remarkable discovery of the sexuality of flowers was first made, it was naturally supposed that each flower was fertilized by its own pollen. But Darwin has shown that in many cases this is impossible, in consequence of the stamens and pistils coming to maturity at different times;[2] and there are some instances of reciprocally dimorphic species of plants—that is to say, plants bearing two kinds of flowers, each of which contains both stamens and pistils; but the pistils of each form can be properly fertilized only by the

Agency of
insects in
fertilizing
flowers.

pollen of the other.[3] Insects are the principal agents in carrying pollen from one flower to another; and it is Darwin's belief that flowers have been endowed with their bright colours (and, if so, no doubt with their nectar also) for the purpose of attracting insects.[4] Insects are useful,

---

[1] Origin of Species, p. 113.   [2] Ibid. pp. 111, 325.

[3] Ibid. p. 320.

[4] Ibid. p. 239. "I have come to this conclusion," he says, "from finding it an invariable rule that when a flower is fertilized by the wind, it never has a brightly-coloured corolla. Again, several plants habitually produce two kinds of flowers; one kind open and coloured, so as to attract insects, the other kind closed and not coloured, destitute of nectar, and never visited by insects."

no doubt, not only by bringing pollen from other flowers, but also, in those flowers which are capable of being fertilized by their own pollen, by brushing it on to the stigma; and it is probably impossible in all cases to separate these two functions; but, after what has been said, we cannot doubt that the occasional introduction of pollen from another flower must be beneficial. Pollen will, no doubt, be brought from flowers of other species; but this will not be injurious—it will have no effect whatever.

Sexuality, and the existence of distinct generative organs, are not the same thing, and do not imply each other. The existence of separate generative organs is only a case of the " physiological division of labour," in virtue of which law every separate function in the ascending scale of organization tends to acquire a separate organ for itself. There are many cases of the action of the reproductive function through distinct reproductive organs without the sexual relation coming into play : the females of some butterflies, for instance, produce true eggs from true ovaries, which are fertile without being fertilized by the male.[1] And, on the other hand, the instance of the lower Algæ, mentioned above, shows that sexuality may exist without separate reproductive organs, or even distinction of sexes ; and that it essentially consists in the union and fusion of germinal matter from two distinct sources. It consequently appears a highly probable conclusion, that sexuality, though a universal law of life, is not an ultimate one, but is to be referred to the necessity for slight changes, in order to keep up the vigour of life. Many of the lower organisms, no doubt, propagate by spontaneous division, as the simpler Algæ; others, by throwing off buds, as the Hydra; others, which are not so lowly organized, by true eggs that have not been fertilized by the male, as the butterflies just mentioned; and others are capable of fertilizing themselves by a truly sexual process, like many flowers. But it appears probable that no organic species

Marginal notes: Sexuality distinct from the existence of separate generative organs: depends on the necessity of slight changes.

---

[1] Spencer's Principles of Biology, vol. ii. p. 214.

o

No species is able to go on doing so for an indefinite number of
can live an
indefinite generations.[1]   It appears probable that any race whatever
time   will at last lose its vigour, and die out, if its life is not, as
without
sexual   it were, renewed by the mixture of germinal matter from
reproduc- another source.
tion.

Varia-   But, whatever may be the ground of the law of sexuality,
bility pro- there can be no doubt of the beneficial effect both of slight
moted by
slight   changes in the conditions of life, and of mixture of nearly
change   allied though distinct races; and it is also true, that changes
of con-
ditions, in the circumstances of life, and mixture of races, tend to
and by   promote variability.[2]
mixture
of races.   I am now speaking of spontaneous variation. This, as
          I have mentioned at the beginning of this chapter, is a
          distinct thing from functionally-produced change; and I
          propose to call the tendency of a race to vary spontane-
Varia-   ously, *variability*, and its aptitude for acquiring function-
bility and ally-produced changes, *modifiability*. These two properties
modifi-
ability. are different; but there is, I think, a good deal of reason
          for believing that they are, to a great extent, found together
          —at least among the highest animals. The wonderful
          modifiability of the instinctive faculties of the dog, which
          has enabled him to acquire totally new instincts under
          domestication, must, I think, be in some way connected
          with the variability of his form, which has given origin
          to such different races as the greyhound and the
          terrier.

Sponta-   Spontaneous variations may be defined as those differ-
neous vari-
ation, how ences of offspring from parent, and of the offspring of the
far con- same parents from each other, for which no reason can be
nected
with the assigned.   These do not come under the law of habit, in
laws of   that they do not originate, in virtue of that law, by the
habit: repetition of actions; but they do come under the law of
          habit, in that they are instances of the variability of habit,

---

[1] Darwin's Origin of Species, p. 109.

[2] See Darwin's Origin of Species, p. 21.   The statement that changes in
the conditions of life tend to promote variability is repeated several times
throughout the work, and is illustrated by the examples of various
domestic animals and cultivated plants.

and also in their tendency to become hereditary, and in
their greater tenacity the longer they have been inherited
through successive generations.

.There is this important difference between functionally-
produced changes and spontaneous variations, that func-
tionally-produced changes are necessarily produced during
the lifetime of individuals, though they may be transmitted
to the offspring; but spontaneous variations appear to take
their rise in the act of originating a new individual. They *originates*
sometimes arise in the production of a new individual *only with*
new in-
without sexual generation, as in the case of plants that *dividuals.*
produce "sports" from buds; for every branch produced
from a bud may in some sense be regarded as a new indi-
vidual.[1] A long list could easily be given of " sporting " *" Sport-*
plants : by this term gardeners mean a single bud or offset, *ing "*
plants.
which suddenly assumes a new and sometimes very dif-
ferent character from that of the rest of the plant. Such
buds can be propagated by grafting, &c., and sometimes by
seed. These sports are extremely rare under nature, but
far from rare under cultivation.[2] Variations, or new varie- *Variations*
ties, are, however, oftener obtained by sexual generation. *are most*
abundant
There are some species—as, for instance, the potato— *in cases of*
which have been rendered so variable by cultivation, that *sexual*
generation.
new varieties are produced whenever they are raised from
seed. Reproduction from seed is reproduction by sexual
generation; and, as I have shown, there is some degree of
mixture of race in all sexual generation. This is probably
to be regarded as true even of a flower that fertilizes itself;
for the anthers and the pistils, though in the same flower,
are distinct elements of the organism. But of course the
mixture of race is greater when the pollen is brought from
another flower on the same plant, and greater still when it
is brought from another plant. And, as already stated,
the greater the mixture of races, the greater is the pro-
bability of variation in the offspring—provided, of course,
that they are races that breed freely together, and produce
fertile offspring; for the tendency to variation does not

[1] See Note at end of chapter.
[2] Darwin's Origin of Species, p. 9.

wear out, but appears to increase in the first few genera-
tions. When the breeds that are crossed are very different,
the variation is so great that it is nearly impossible to
obtain a permanent breed of character intermediate between
the two parent breeds.[1]

Inter-
mediate
breeds are
difficult to
obtain.

    Mixture of race, which is thus a stimulus to variation,
also facilitates reversion to ancestral characteristics. Thus,
in all the domestic varieties of the pigeon, birds are occa-
sionally found that have reverted to the blue colour, with
black bars on the wings, and other characters of the wild
rock-pigeon, from which the domestic breeds are descended;
and such specimens are particularly abundant where the
breeds have been mixed.[2] Sometimes, where very unlike
breeds have been mixed, the offspring are neither inter-
mediate between the parents nor irregularly variable; but
some of them resemble one parent, and some the other.
Something of this is very common in families of children,
where some generally resemble the father's family, and
some the mother's. But the most remarkable instance I
know is that of the otter, or Ancon sheep, an accidental
variety that appeared at one time in North America, and
was preserved by the farmers, in consequence of its being
unable to leap fences. It began with a single lamb; and
when the otter sheep were crossed with the common kind,
some of the lambs resembled the ram, and others the ewe;
but no mixed breed was ever produced.

Reversion
common
in mixed
breeds.

Otter
sheep.

    Variation among animals is usually gradual, being but
slight in a single generation, though, under favourable cir-
cumstances, it may accumulate through successive genera-
tions. When it is considerable, as in the case of the
otter sheep just mentioned, it is usually in some degree
monstrous.[3] Sudden variation is much commoner among
plants, as in the case of " sporting " plants. The following
cases of the sudden origin of what appear to be permanent

Variation
usually
slow
among
animals:

often sud-
den among
plants.

[1] Darwin's Origin of Species, p. 21.   [2] Ibid. p. 188.
  [3] It is impossible to draw the line where mere variation ends and
monstrosity begins. A variation of a degree that would be called a
monstrosity in an animal, would be called only a "sport," or a singular
variety, in a plant.

varieties of plants are mentioned on the authority of
M. C. Naudin [1]:—" The first case mentioned is that of a
poppy, which took on a remarkable variation in its fruit— Poppy.
a crown of secondary capsules being added to the normal
central capsule. A field of such poppies was grown, and
M. Göppert, with seed from this field, obtained still this
monstrous form in great quantity. Deformities of ferns Ferns.
are sometimes sought after by fern-growers. They are
now always obtained by taking spores [seeds] from the
abnormal parts of a monstrous fern; from which spores
ferns presenting the same peculiarities invariably grow. . . .
The most remarkable case is that observed by Dr. Godron,
of Nancy. In 1861 that botanist observed, amongst a
sowing of *Datura tatula*, the fruits of which are very *Datura*
spinous, a single individual of which the capsule was per- *tatula.*
fectly smooth. The seeds taken from this plant all fur-
nished plants having the character of this individual. The
fifth and sixth generations are now growing without ex-
hibiting the least tendency to revert to the spinous form.
More remarkable still, when crossed with the normal
Datura tatula, hybrids were produced, which, in the second
generation, reverted to the two original types, as true
hybrids do."

The last statement may be compared with what has
been mentioned above, as to the impossibility of obtaining
a breed intermediate between the common and the otter
sheep.

Very little is known about the laws of variation. We
may, however, make the following statements with con-
fidence :—

Variation is not always going on, nor does it go on in Only some
every part of an organism at once. Many races produce races are
variable,
hardly any variations ; and, among the variable ones, some and some
characters
characters are more variable than others; and when a of those.
character has recently varied, it is apt to continue variable,

---

[1] Quoted from the *Comptes Rendus,* in the Quarterly Journal of Science,
October 1867, p. 527.

having, as I have already expressed it, acquired a habit of varying. Thus, among the domestic races of animals, the most variable characters are those in which each breed differs from the other breeds of the same species; and these are characters which, having arisen by variation since the races were first domesticated, must have varied conspicuously in a time which is very short in comparison with the lifetime of a species.

Correlation of variations. Certain variations are habitually found together, or, as Darwin expresses it, are correlated. The nature of the correlation is sometimes quite unintelligible: thus, perfectly white cats frequently have blue eyes instead of green, and are deaf.[1] But in many cases it is to be referred

Homologous parts vary together. to the simple and intelligible law, that homologous parts tend to vary together. Thus, similar characters on the opposite sides of the body are so much a matter of course, that any exception to the law is regarded as a monstrosity —as, for instance, when the hands are of unequal length; and, in the same way, the hands and the feet, which are homologous parts, usually have similar characters. It would be very difficult to find a person with large hands and small feet, or the reverse.

Mental and motor characters are more variable than formative ones. Throughout the organic creation some classes of functions appear to be much more variable than others. Mental and motor habits are much more variable than formative ones: thus, in man, mental characters are incomparably more variable than bodily ones as between different individuals, and also more modifiable by education and circumstances. The same appears to be true of the domestic races of animals, at least of the more intelligent ones. As instances of the changeableness of purely motor functions may be mentioned the cases of the domestic hen, duck, and goose, which from disuse have nearly lost the power of flight, without the muscles of their wings being diminished in size in any proportionate degree. These are cases of functionally-changed habit. The habit from which the tumbler variety of the pigeon derives its name is a far more extraordinary case, and is certainly unique among

---

[1] Darwin's Origin of Species, p. 12.

flying animals: it must have originated in some spon-
taneous variation.

Among formative functions it appears to be a law that The
the minutest structures are the least variable. Thus, the minutest
structure
form of the leaves of any species of tree is in general is the least
variable.
tolerably constant, while the form of the entire tree is
much more variable; and the form of organs appears to be Organs
much more variable than the structure of tissues. Very and tissues.
little is yet known on this subject. Darwin has made a
vast collection of facts showing the variability of organs;
but no one has yet made a similar microscopic examination
of various tissues, for the purpose of ascertaining the
degree and the limits of their variability. There is, how-
ever, a remarkable constancy of microscopic structure
throughout the same species of organisms; thus, a small
fragment of a tooth, even when in a fossil state, is often Teeth.
enough for the identification of a species;[1] and the same
is true of shells, even when their forms are subject to Shells.
considerable variation.[2] Dr. Beale makes the following
striking remark on the constancy of histological characters
throughout the same species, and their distinctness from
those of other species:—

" The anatomical differences between corresponding tis-
sues of closely allied species are often so distinct that the
anatomist familiar with them could distinguish the one
from the other. For example, it would be difficult to state
in few words the difference between the unstriped muscular Muscular
fibres of the bladder of the hyla [or tree-frog], of the tissue.
common frog, and of the newt, and yet there is a recog-
nisable difference; and corresponding differences can be
demonstrated in other textures, if a comparison be care-
fully instituted."[3]

The subject, however, needs systematic investigation. Investi-
The variability of external form is visible to the eye in gation
needed.

[1] Carpenter's Comparative Physiology, p. 152.
[2] My friend the Rev. John Grainger, of Dublin, informs me that the
structure of shells presents little that is characteristic of particular species,
but the *sculpture*, or external markings, often enables the species to be
determined from very small fragments.
[3] Beale's edition of Todd and Bowman's Physiology, p. 41.

The dog and the pigeon. many instances, especially in the races of the dog and of the pigeon, which are so unlike each other that no one, on merely seeing them, would guess that they belonged to the same species ; and yet it is proved that they do belong to the same species, in both cases, by the fact that they breed freely together, and, in the case of the pigeon, by satis-factory evidence that all the domestic races have originated since the bird was first domesticated.   If similar varieties exist in the microscopic characters of any species, they will not be obvious to the eye, but must be sought for.

The most constant characters in species are also the most constant in classes. It is to be observed that those characters which are most constant and least liable to variation, as between individuals and between mere varieties of the same species, appear, as a general rule, to be also the most constant throughout whole wide classes.   Thus, the structure of nerve, muscle, and bone is much more constant between species of the same order, and between orders of the same class, than is the distribution of the nerves and the form of the muscles and bones.   To mention a very remarkable

Bones of pterodac-tyle. instance : the skeleton of a pterodactyle, which was a reptile organized for flight, has a strong resemblance in its general outline to that of a bird ; but a microscopic exami-nation of a fragment of one of its bones shows it to have the structure belonging to the bone of a reptile.[1]   This law, that the characters which are most constant throughout the species are also the most constant throughout the group to which the species belongs, is, as I agree with Darwin in thinking, of great importance in explaining the origin of species.   I only refer to it here as affording a strong presumption in favour of the truth of the opinion I have advanced, that the minutest structures are the least variable.

The lowest organisms are most variable. The lowest organisms, on the whole, are the most variable.   Vegetables are, on the whole, much more lowly organized than animals, and they are much more variable in form.   The Algæ, which are among the lowest vege-tables, are peculiarly variable ; and among the Foramini-fera, which are among the lowest animals, the variability

[1] Carpenter's Comparative Physiology, p. 140.

is so great, and the intermediate forms present such
innumerable gradations, that it is utterly impossible to
fix the species.[1]

"When any part or organ is repeated many times in the Parts
structure of the same individual, as the vertebræ in snakes repeated
and the stamens in polyandrous flowers, the number is times are
variable; whereas the number of the same part or organ, variable.
when it occurs in lesser numbers, is constant."[2]

Between these two laws—that low organisms are vari-
able, and that the number of often-repeated parts is
variable—there is this connexion, that multitude of similar
parts is a mark of low organization. And we may assign Reason of
this very obvious reason for both, that the lower the organ- these two
ism, the more will its form be a matter of indifference; laws.
and the greater the number of parts, the more will their
exact number be a matter of indifference. The form of a
sea-weed must be nearly a matter of indifference to its
health and life; but any great deviation from the normal
form in one of the higher animals constitutes deformity,
and is destructive. And, similarly, a pair of legs more or
less may make no difference to a centipede, but it is an
affair of life or death to a quadruped.

The laws of ordinary spontaneous variation, as stated Summary.
above, may be thus summed up:—

Spontaneous variations are quite distinct from func-
tionally-produced modifications. Spontaneous variation
occurs only when a new individual comes into existence.
It occurs oftener in cases of sexual than of non-sexual
propagation, and is stimulated by mixture of races and by
changes in the external circumstances of life.

Some races are more variable than others; and when a
race has become variable, some characters are more variable
than others. When a race, or a character, begins to vary,
it will continue to vary for an indefinite time.

Homologous parts tend to vary together, and there are
other correlations which cannot be reduced to any law.

---

[1] Carpenter on the Foraminifera, published by the Ray Society, 1862.
[2] Darwin's Origin of Species, p. 176.

Mental and motor characters are more variable, as well as more modifiable, than formative ones.

Among formative characters, the minutest structures are the least variable.

The lowest organisms vary most; and when there are many similar parts, their number is variable.

I believe that very little more than what I have stated is known on the subject of ordinary spontaneous variation. But, as I have mentioned at the beginning of this chapter, besides functionally-produced modifications and sponta-

Third class of changes. neous variations, there is a third kind which it is difficult to class. These take place only in organisms of low type.

Crystals vary with the medium from which they are deposited. It has been mentioned in the chapter on Crystallization, that crystals of the same species—that is to say, of the same chemical composition and the same "crystallographic elements"—often differ very much in form, according to the character of the medium from which they have crystallized. This variability is regular; that is to say, the same alteration in the medium determines the same peculiarity in the form of the crystal. Thus, " common salt crystallizing from pure water forms cubes; but if the water contains a little boracic acid, the angles of the cubes are truncated." " Carbonate of copper, crystallizing from a solution containing sulphuric acid, forms hexagonal tabular prisms; but if a little ammonia is added, the form changes to that of a long rectangular prism with secondary planes on the angles; if a little more ammonia is added, several varieties of rhombic octahedra appear." [1]

Similar variations in fungi. Similar variations from similar causes appear to take place among many low organisms, especially among those Fungi which constitute mould. We have not what can be called direct evidence of this; but there is evidence that the forms of the inferior Fungi are extremely variable; [2] and it is scarcely possible to doubt that the various forms of Fungi which are characteristic of particular situations

[1] P. 75.

[2] " It is asserted by Fries, that out of a single species of *Thelephora* more than eight genera have been constructed by various authors." (Carpenter's Comparative Physiology, p. 214.) Compare what has been said above on the variability of the Foraminifera.

are not all really distinct species, but that the same germ will develop into different forms, according to the soil on which it falls. "Thus, no *Puccinia* but the *Puccinia rosœ* is found upon rose-bushes, and this is seen nowhere else; *Omygena exigua* is said to be never seen but on the hoof of a dead horse; and *Isaria felina* has only been observed upon the dung of cats deposited in humid and obscure situations."[1] We can scarcely believe that the air is full of the germs of distinct species of Fungi, of which one never vegetates until it falls on the hoof of a dead horse, and another till it falls on cat's dung in a damp and dark place. It is probable—indeed, in my mind, certain—that among the lower Fungi, as among crystals, the same species assumes different forms according to the medium in which the development takes place.

Variations of this kind are clearly not of the class of spontaneous variations, for the form is determined by the medium in which the development takes place. It is difficult to say whether they are functionally produced. The inferior Fungi appear to be very susceptible of functionally-produced modifications: thus, they are sometimes developed in liquids, and then they assume very much of the character of Algæ.[2] But it is difficult to see how any change of form could make one of those low Fungi which constitute mould better suited to a new habitat; and I incline to think that the variations by which the same germ of mould develops into different forms, in different situations, is rather analogous to the variations of crystalline form of which I have spoken than to any result of the laws of habit. *Functionally produced modifications in fungi.*

The power of some of the lower organisms to develop into different forms in different situations is probably the *Origin of Entozoa.*

---

[1] Carpenter's Comparative Physiology, p. 214, note.

[2] Ibid. p. 198. A remarkable instance of the change caused by removing a fungus to a new medium is mentioned in a communication from Mr. Varley to the Microscopical Society of London (Zoologist, 1850, p. 2674). After describing a fungus that often destroys the common house-fly, the report goes on :—" By immersing the fly in water, Mr. Varley found that the mode of growth of the fungus was altered, the heads being no longer produced, and the whole plant becoming long, crooked, and filamentous."

explanation of what formerly was the most perplexing question in biological science—I mean the origin of the internal parasites of animals. The germs of these, I have no doubt, have been in all cases originally introduced from without, either in the food or through the skin, and have been developed into different forms from those which they would have assumed had their development taken place elsewhere. This conjecture is almost proved by the discovery of the fact that many of these internal parasites, or
Their meta-genesis. Entozoa, alternate by metagenesis [1] with animal forms that inhabit the earth or the water.

NOTE.

INDIVIDUALITY.

Indi-viduality, difficult to define among the lower organisms. AMONG the lower organisms, it is nearly impossible to define what an individual is. The single cell of one of the lowest Algæ can scarcely be described as other than an individual, and yet it is homologous with the cells that combine to form the filaments of *zygnema*, or the fronds of the higher Algæ. The separate *hydra* is homologous with each polypite of the compound Hydrozoa; yet the latter are united into one compound organism, in much the same way that the leaves of a tree are united. In fact, the word "individual" is scarcely applicable;
Morpho-logical units of different orders. the expression, "morphological unit," proposed by Herbert Spencer, is better, as we can speak of morphological units of different orders. Among the higher orders of plants, the morphological units of the first order are the cells; these, by combination, form the units of the second order, which are the leaves with their stalks; these combine into units of the third order, that is to say, into branches, or axes (understanding by this term the product of a single bud), and the branches into trees : just as the unit of organization in an army may be successively taken to be the individual soldier, the company, and the regiment.

[1] Metagenesis, a parallel word to metamorphosis, and signifying that two forms produce each other alternately. Thus, to take an instance from a different class, many hydra-like forms produce medusæ, and the medusæ again produce hydra-like forms.

CHAPTER XVII.

THE PROBLEM OF THE ORIGIN OF SPECIES.

HAVING in the last two chapters considered the laws
of habit and variation, we are now in a position, not
indeed to solve, but to state, the question of the origin
of species.

In the chapter on the Chemistry of Life, we have seen
that vital properties are not a resultant from the ordinary
properties of matter; and that the origin of life, as much
as the origin of matter and energy, must, in all probability,
be directly referred to Creative Power. But the question
of the origin of the distinct species and classes of living
beings is quite another question, and it may be thus
stated :—

We have seen, in the chapter on Organization, that
organization is not the cause, but the effect of life: vital-
ized matter has a tendency to produce organization. We
have also seen, in the last two chapters, that the characters
of species are not absolutely invariable, but that modi-
fications may be functionally produced in the lifetime of
the individual, and variations, sometimes of very percep-
tible magnitude, may arise spontaneously in the production
of new individuals; and also that, in all probability, the
germs of many of the lower organisms, if developed in Have all
a new habitat, will produce new forms. Does not all this species been
make it probable that distinct species, and even classes, separately
created, or
have not been separately created, but that they have been derived
all derived by descent, with modification and variation, from a few
original
from one, or at most a small number, of germs—mere germs?

minute masses of germinal matter that were once vitalized
by Creative Power ?[1]

I believe the latter. Where I dissent from Darwin.   I believe they have been so derived, and in this I agree
with Darwin. But I must again repeat here that I am not
a believer in what is usually, and quite accurately, called
" Darwin's theory." According to Darwin and his disciple
Herbert Spencer,[2] the laws of habit and variation are
sufficient to account for the whole process of modification
by which the most highly organized vegetables and animals
have been derived by descent from their first vitalized but
unorganized germs. I altogether differ from this : I think

I believe in a guiding Intelligence.   the process of modification proves the agency of an Intel-
ligent Power, acting through and controlling the laws of
habit and variation, just as all the vital forces act through
and control the inorganic ones.

But before we discuss the agency by which the modi-
fication has taken place, let us consider the proofs—which,
in my opinion, are overwhelmingly strong—that the modi-
fication has taken place. Several chapters, however, will
be required to state the proofs even in outline ; and in this
chapter I intend only to reply to some of the more obvious
and important objections.

Development theory, not contrary to experience.   It is often said that any theory of the origin of species
by descent from other species is contrary to experience,
because all experience shows that every species produces
its own kind, and not some other. This objection is not of
much force. What is true within the limits of a very short
experience is not necessarily true in a much longer time.

Changes in language.   Thus, languages do not, at least in general, change per-
ceptibly in a lifetime; but we know that they change in
historical time : thus, Latin has given origin to the entire
group of modern Romanic languages in less than two

Geological changes.   thousand years. The outlines of continents and the heights
of mountains are not perceptibly changeable in historical
times ; but we know that in geological time they are as
fleeting as the outlines of a cloud. So, if it is proved, as it

---

[1] See Note at end of chapter.

[2] In calling H. Spencer a disciple of Darwin, I do not mean to disparage
the great originality, or the wonderful ingenuity, of his work on Biology.

is, that organisms are in any degree susceptible of variation,
that variation may become indefinite in amount, if inde-
finite time is granted for the variations to take place, and
to be added together.

I cannot admit that there is any intrinsic improbability No in-
in the derivation of the highest organisms by descent from improba-
the lowest: I think the improbability is all the other way. bility.
It would be contrary to all the analogy of nature to sup-
pose that any of the highest works were ever produced at
once and by a single creative act; but it is in accordance
with all that we know of the ways of nature to suppose
that species, like individuals, have been developed out of
simple germs.   When we know that every individual Analogy of
organism, vegetable and animal, has been developed out individual
of a simple structureless germ, and that there is no test, ment.
chemical or microscopic, by which the germ of one organism
can be distinguished from that of another, no matter how
unlike may be their mature forms; and when we know
that every organic species must have had an origin, is it
not most natural to believe that the origin of the species
has been parallel to that of the individual? The reason
why the theory of the origin of species by development is
so often regarded as improbable, and as having at least a
strong presumption against it, is chiefly, I believe, that it Subject
has not yet had time to become familiar.   It was impos- familiar.
sible that the development theory could be entertained at
all until the very great antiquity of the earth was known;
for, so long as it was believed that the order of nature
was only coeval with human history, it was a necessary
inference that the organic creation came into existence all
at once, at the beginning of things. And it was impossible
that the development theory could be argued on a right
basis until it was proved that every individual is developed
from a perfectly simple and unorganized germ, and until
the old notion that the germ was a folded-up miniature of
the perfect form was disproved.

A really scientific objection to the development theory is Separation
the general fact that the union of distinct species will not of species
produce offspring, or at least not fertile offspring; and it sterility,

has been a very generally received opinion that this cri-
terion of distinction between species is absolute ; that the
distinction of species thus made and thus marked is a per-
fectly impassable barrier ; and that, consequently, not only
the first origin of life, but also the origin of every distinct
species, needed a distinct act of Creative Power.   In my
opinion, however, Darwin has fully answered this objection
by the great mass of facts brought together on this subject
in the chapter on Hybridism, in his great work on the
" Origin of Species."   As that work is very well known
and very readable, I will only state his conclusions in the
barest outline ; some of them have been stated already in
the last chapter, but I will repeat them here.

It is true that similar organisms produce offspring
together, and that unlike organisms will not produce
not abso- offspring together.   But it is not true that this distinction
lute.   is rigid and absolute ; on the contrary, it admits of grada-
tion.   Between perfect mutual fertility and perfect mutual
sterility there are an indefinite number of gradations.
Sometimes forms that are regarded as distinct species are
perfectly fertile with each other, taking the production of
the average number of seeds as the test of perfect fertility ;
sometimes forms that are regarded as only varieties of the
same species are not perfectly fertile with each other.   The
fertility of different varieties and species with each other
admits of various degrees, as estimated by the number of
seeds produced.   Sometimes hybrids are perfectly normal
organisms ; sometimes they are healthy, but infertile ;
sometimes they are weak, and perish early.

Reason of   It is important to observe that we do not know on what
mutual
sterility   the mutual sterility of distinct species depends.   It is cer-
unknown.   tainly not on mere visible unlikeness : the various domestic
breeds of pigeons are all perfectly fertile together, and yet
they are more unlike in external appearance than many
animals are to each other which are universally classed as
distinct species, and most probably are not fertile together.[1]

[1] I say *most probably*, because the fact is very difficult to ascertain, as
few animals breed freely in confinement.   The case of the mule between
the horse and the ass, however, is an important one on this subject ;

The same is true of the various breeds of the dog: no one, merely by seeing them, would think that a greyhound and a terrier were of the same species. It is quite possible— though I only offer this as a suggestion for which it may never be possible to find proof—that mutual sterility depends on the length of time that has elapsed since the two stocks separated. The various races of pigeons have all been produced under domestication, and consequently during the historical period ; but the origin of wild races may go back into geological time : so that, although the most unlike races of pigeons are more visibly unlike than the horse and the ass, the stocks of the horse and the ass may have diverged from each other hundreds of thousands of years before the stocks of the various races of pigeons began to diverge; and this may be the sole reason why all breeds of pigeons are mutually fertile, while the horse and the ass are not perfectly so.

Sugges-tion on the sub-ject.

Another very obvious objection to the development theory is, that if species have been formed by slow transi-tion, by descent, from one form to another, we ought to find innumerable transitional forms; but instead of finding these, we find that each species is quite distinct.

Transi-tional forms,

This is partly answered by the statement that in very many cases each species is *not* quite distinct, and that we *do* find a great variety of intermediate forms ; so that—what appears a strange paradox and yet is true—it often happens that the more thoroughly a genus is known, the more difficult it is to determine which of its members are species and which only varieties.[1] But this answer is utterly insufficient. If species have been formed by slow transi-tion, only a very small proportion of all the forms that must have existed are now living.

often still in exist-ence,

but mostly lost.

But why do we not find their remains entombed among the rocks ?

To this objection Darwin has, I think, given a conclusive

it is well known to be healthy, but not fertile. With cultivated plants experiments of this kind are in general easy.

[1] Darwin's Origin of Species, p. 58.

Imperfec-
tion of the
geological
record.

reply in his chapter on "the Imperfection of the Geological Record." On this subject, as on that of Hybridism, it is only necessary for me to state his conclusions in the barest outline.

Soft-bodied animals, like the naked worms and mollusca, are not preserved at all; they perish without leaving any record of their existence. The same is mostly true of land animals, though for a different reason. It is only in the rarest cases that land animals can die under such circumstances as to be buried, and afterwards fossilized. As a rule,

Destruc-
tion of
fossils.

it is only the hard parts of aquatic organisms that will be fossilized and preserved; and when they are so preserved, the older the fossiliferous beds, the less will be the chance of their preservation to our age. "The stir of the forces whence issued the world"[1] is not quiet yet, and never has been quiet. The deposition of new strata never ceases; and it must be remembered that, as the quantity of matter in the world is unchangeable, if there is deposition going on in one place, there must be an equivalent amount of

Denuda-
tion.

denudation somewhere else—that is to say, an equivalent amount of destruction of old strata; though we habitually forget this, because we see the deposit, and do not see the denudation.

Besides the effect of denudation in destroying old fossili-

Metamor-
phism.

ferous beds, there is the effect of metamorphism—that is to say, the chemical effect of heat. It was first pointed out, I believe, by Sir John Herschel,[2] that (granting, what is unquestionable, the theory of the earth's central heat) any deposition of strata must raise the temperature of the strata underneath, exactly in the same way that putting on a warm coat raises the temperature of the skin. Such a rise of temperature, if sufficiently great, will cause a metamorphic change in the strata so covered, and will destroy their fossils. As metamorphism from this cause, as well as from the intrusion of igneous rocks, is not an exceptional but a normal action, and as the same is true of denudation,

[1] Matthew Arnold.

[2] See his letter to Sir C. Lyell, in the Appendix to Babbage's Ninth Bridgewater Treatise. Darwin has made no use of this argument.

it follows that metamorphism and denudation—fire and water—are incessantly destroying the ancient records of creation; so that all that geologists can ever hope to recover are the latest leaves of the volume, and these in but a fragmentary state, because a large proportion are covered by the sea, and others buried inaccessibly deep.

With all this, it remains true that many intermediate forms have been discovered; and, what is a most important fact, no class—no type of form—has been found among fossil species fundamentally unlike all living classes. As has been truly remarked, all fossil forms can be arranged either in or between living groups. To mention what is, perhaps, the most striking instance of this : till very lately, the class of birds appeared to be isolated from all others ; but recent discoveries have proved—or at least all but proved—the former existence of an entire order connecting the birds with the reptiles. *Discovery of intermediate forms.* *Reptilian birds.*

Another objection to the development theory is that raised by Dr. Beale, and alluded to in the last chapter; namely, that although the forms and external characters of species are variable, there is no proof that their histological or minute structural characters are so. On this subject we are as yet, I believe, quite too ignorant to base any argument, either the one way or the other. My own opinion, however, based purely on the analogy of the case, is this : that as structure *differs* between species and between classes, but differs less than form, so it will be found that structure *varies* within the limits of the same species, but varies less than form. *Variability of histological characters.*

Having thus briefly touched on the principal arguments against the development theory, I will go on with those in its favour. I cannot as yet enter on the subject of the process by which the development of new species has been brought about, and its causes; but I will here state in outline some reasons for believing in the development theory, which are to me of great weight, though they are so far from obvious that they appear to have been unnoticed until the publication of Darwin's great work.

Species are permanent varieties.
If the development theory is true, and if all species whatever, or all the species of any wide group, are descended from the same original ancestor, then, as Darwin has expressed it, "species are only well-marked and permanent varieties;" and the species of a genus stand to each other in the same relation as do the varieties of a species. Such is shown to be the case by a great amount of evidence which Darwin has collected, and arranged in a way that could only have been done by one combining his vast knowledge of the details of natural history with his power of seizing on the essential relations of a subject. As his "Origin of Species" is a well-known and very readable book, it is only necessary to state the following facts in the barest outline.

Varieties are most numerous where species are so.
"Where many large trees grow we expect to find saplings;" and when a form has been varying much within recent geological time, so as to form many species belonging to one genus, we may expect to find that it is still varying. Such is the fact: if large genera (that is to say, genera containing many species) are compared with small ones, it will be found that, on the average, a greater number of the species of the large genera than of the small ones present varieties; and those which do present varieties, present a greater number of them. These results, of course, are not uniform, only average ones.[1] What is a fact of

Aberrant genera are poor in species.
exactly the same order, aberrant genera (that is to say, genera that are very peculiar, and not nearly akin to any others), are nearly always small genera.[2] On the theory of development, an indefinite number of intermediate forms must have existed formerly. A genus has become aberrant by the extinction of all the species and genera that formerly connected it with other known forms; and as the same causes, whatever they are, that determine the increase or the extinction of a species or of a genus usually act nearly alike on kindred species and genera, the causes that make a genus aberrant by destroying the kindred genera will also make it poor in species by destroying many of its species. Such genera are *Ornithorhynchus* and *Lepidosiren*.

---

[1] Darwin's Origin of Species, p. 65.   [2] Ibid. p. 508.

These may be compared to trees which have been left alone by the gradual destruction of their neighbours, and have at the same time lost many of their own branches.

A different fact, pointing in the same direction, is the following:—In the chapters on Habit and Variation we have seen that if a character begins to vary, it will continue to vary for an indefinite time. It is a case of this law, that when variations have arisen under domestication, and consequently a very short time ago, geologically speaking, the part that has varied, and is characteristic of the variety, continues to be the most variable part of the organism. The varieties of the domestic pigeon are the best instance of this.[1] But what I wish to remark is, that what I have just stated of the varieties of a species is equally true of the species of a genus. When any part in one species of a genus is unlike the corresponding part *Characters variable* in the other species, whether in size or in shape, or in any *as between* other way, the same part is also usually variable as between *species are* the different varieties, and between the different individuals *the species.* of the species; or, what is saying the same thing in more concise language, specific characters are more variable than generic ones.[2] For instance, in some groups of beetles the *Wings of* presence or absence of wings is of no importance in classi- *beetles.* fication: there are genera in which some species have wings, and others have none; and sometimes this character is variable even between individuals of the same species. This fact is what might be expected on the supposition, that species are only " well-marked and permanent varieties:" on the supposition of the separate creation of every species, it is utterly inexplicable.

Reversion to ancestral characters is closely connected *Reversion* with variation, and is sometimes due to the same cause; *in varie-ties* namely, mixture of races. In all the breeds of pigeons, individuals are sometimes found that have reverted to the plumage of the rock-pigeon, from which the domestic breeds are descended; but these are most numerous when two breeds have been crossed. Crossing of the breeds is also a cause of general variation.

---

[1] Darwin's Origin of Species, p. 180.   [2] Ibid. pp. 177, 182.

and in
species.

Species of
Equus.

That which is true of the varieties of the pigeon is also true of the species of the genus Equus. The zebra and other species of Equus are striped: the ass usually has stripes on the back and shoulders only, though sometimes on the legs also: the horse, in general, has no stripes at all; but horses are occasionally found with stripes on the back and shoulder, and in the Kattywar breed in India these are usual, and bars on the legs are common. The fact of these stripes being characteristic of other species of the genus, and occasionally appearing in the horse, suggests that their appearance in the horse is a case of reversion; that all the species of Equus, like all the varieties of the pigeon, are the descendants of one ancestral species, and that the appearance of these stripes is a case of reversion to its characters. What greatly strengthens this presumption is, that mixture of race between different species of Equus, as between different varieties of the pigeon, increases the tendency to the production of these characters. Bars on the legs are much more common in the mule between the horse and the ass than in either the horse or the ass.[1]

Laws of
variation

We thus find this law of variation, that characters which are variable as between the species of a genus are also apt to be variable as between the varieties and between the individuals of a species. And we also find this law of

and of
reversion.

reversion, that individuals are sometimes found which present what appears to be the character of the original form from which all the varieties of a species, or all the species of a genus, have been descended. I believe that these laws are true on a much wider scale,[2] and will elucidate relations between species, not only of different genera, but of different classes.

The law, that those characters which are variable as between the species of a genus are also variable as between

[1] Darwin's Origin of Species, p. 191.

[2] Darwin thinks that the occasional formation of a sixth finger in man may be due to reversion to the characters of a remote ancestor near the bottom of the vertebrate scale. No living species of air-breathing vertebrate has more than five digits, but that number is exceeded in fishes and some extinct reptiles. (Darwin's Variation under Domestication, vol. ii. p. 16.)

the varieties of those species, is, I think, only a particular Extension
case of a much wider law, which may be thus stated:— of the
The wider a group to which any character belongs, the less is stated law
that character liable to exceptions. Thus, for instance, jointed tion.
legs are a character of all the higher Articulata, and they
are found in every species of all their classes, without a
single exception.[1] Wings, on the contrary, are found only in Wings of
the class of true or hexapod insects ; and, though general, insects.
they are by no means constant in their class.   Another
instance of this kind is that of the respiratory organs in the Branchiæ
three allied molluscan classes of Gasteropoda, Heteropoda, of mol-
and Pteropoda.   Most members of these classes have dis- lusca.
tinct respiratory organs ; but their occurrence is not uni-
versal, as some of them respire through the general surface
of the body.   When they do occur, their position is very
variable as between the various families.   In *Firoloïdes
Desmarestii,* a heteropod, there are none, though they occur
in some nearly allied species ; and in one of these, by
name *Atlanta Lesuerii,* some individuals have them, and
others not.[2]   Another instance of the same kind is that of Develop-
the extraordinary larval forms presented by some of the ment
Echinodermata in the course of their development.   This dermata.
peculiar mode of development, of which I shall have to
speak in a future chapter, " in each order appears to be
exceptional ; and in certain cases it is known to be carried
to its most abnormal degree in one species, while in a
closely allied species of the same genus the mode of repro-
duction differs but slightly from the ordinary invertebrate
type.   It seems highly probable that even in the same
species the development and independence of the first
zooid may be carried to a greater or less degree according
to circumstances." [3]

   The other law which we have seen to be established, Extension
that varieties tend to revert to the characters of the of the

   [1] Except, perhaps, among the lowest of the acari, or mites.
   [2] Huxley on the Morphology of the Cephalous Mollusca (Philosophical
Transactions, 1853).
   [3] Dr. Wyville Thomson on the Etymology of the Echinodermata
(Natural History Review, July 1863).

<div style="margin-left: 1em;">above-
stated law
of rever-
sion.</div>

ancestor of the species, and species to the character of
the ancestor of the genus, is, I believe, only a case of a
principle which is true far beyond the limits of species and
genera. I believe that reversion sometimes occurs to the
characters of very remote ancestors indeed, from which the
species in which the reversion occurs is separated, not only
by many myriads of generations, but by very profound
changes.

<div style="margin-left: 1em;">Circular
and bilate-
ral flowers.</div>

One instance of this is among flowers. It can scarcely
be questioned that the normal form of flowers is circular,
and that (supposing the development theory to be true)
flowers of bilateral[1] forms have been derived from circular
ones by descent, with modification. It is to be observed,
that flowers cannot be divided into two classes according
as they are circular or bilateral: all the rose tribe have
circular flowers, and all the foxglove tribe have bilateral
ones; but among the geraniums this character is variable
within the genus—indeed, I believe, within the species.
Individual flowers are sometimes found which are circular,
though belonging to bilateral species. This variation is

<div style="margin-left: 1em;">Peloria.</div>

common enough to have received a name, " peloria," and,
on my view, it is a case of reversion.

Another instance of what I believe to be reversion is far

<div style="margin-left: 1em;">Non-
sexual
generation</div>

more extraordinary. Non-sexual generation is usually a
proof, or at least a concomitant, of comparatively low
organization: it is universal among the lowest animal
forms; it does not occur among the true mollusca, at least
in any ordinary form;[2] but it is common among the marine

<div style="margin-left: 1em;">in worms,</div>

worms, which are about on a par with the Gasteropodous
mollusca in *grade* of organization, though very unlike them
in *plan*. I shall also show reason for believing that all the

---

[1] *Bilateral* may sound pedantic, but I prefer it to *irregular*, which is an
inaccurate expression.

[2] The only known instance of non-sexual generation among the mollusca
is a very extraordinary one, which occurs in their highest class, the
Cephalopoda. The male of the cuttle-fish tribe bears no resemblance to
the female; it is produced by one of the arms of the female being detached
and undergoing a peculiar development, which transforms it into a male
animal, or at least a male organ.

higher Articulata are descended from worms; and I regard
as an instance of reversion to the characteristics of worms,
the fact that non-sexual generation occurs among some of
the lower Crustacea, and also among some genera of winged Crustacea,
insects. The larvæ of Aphis, and of some Diptera, produce and insects.
other larvæ by non-sexual generation; and some butterflies
produce fertile eggs without being fertilized by the male.

Having in this chapter brought forward evidence in
favour of the theory of the production of species by a
process of development, I intend in the next to begin the
consideration of the laws of that process.

NOTE.

In the chapter on the Laws of Habit, I have stated my belief Is there a
that there is no limit to the possible extent of variation, limit to
variation?
if only a sufficient number of generations is allowed. This is I maintain
contrary to the general view, which is that the possible extent the nega-
tive, in
of variation is rigidly confined within the limits of species.   It opposition
has been generally believed till now that variation can only form to usual
belief.
varieties—as, for instance, the domestic varieties of the dog and
of the pigeon have been formed by variation from their original
wild stocks; but that no amount of variation, even though
acting through geological time, could possibly derive two such
species as the dog and the cat by descent from a single ancestor.
This view has been maintained by a singularly able writer on Argument
Darwin's theory in the *North British Review* for June 1867, of *North
British*
who makes the following appeal to the test of fact :— reviewer

The dog varies much in size, as in all other characters, and for the
affirma-
there are some very small breeds of dogs. But the possible tive.
smallness of the dog appears to have reached its limit; for very Limit of
smallness
small dogs are prized by fanciers, who are willing to pay highly in dogs
for them, so that there is an inducement to breed smaller dogs has been
attained.
than the smallest yet bred. The method of doing so would be,
of course, to select the smallest dogs to breed from, and then
select the smallest of the offspring. But this is not done, and
apparently cannot be done. The small breeds of dogs, though
they were originally produced by variation from a much larger

stock, have ceased to vary in the direction of smaller size. The reviewer infers from this that the dog has a specific limit as to size, beyond which it is incapable of varying.

Variation held in check by reversion. I reply to this, that every form has a tendency to revert to ancestral forms; and the limit of smallness in the dog, or the limit of any particular variation in any species, is at the point where the tendency to further variation is balanced by the tendency to reversion. But, though the dog has at present attained a limit at which the tendency to variation in the direction of smallness is held in check, there is no proof that such a limit is so grounded in the laws of life as to be absolutely impassable. All tendencies come under the laws of habit, and consequently may wear out and disappear with mere lapse of time. If, consequently, the smallest breed of dogs now in existence were kept separate and not permitted to mix with any other for a sufficiently long time—say for a thousand years— during which time all individuals that showed any tendency to revert to the larger size of the original stock should be destroyed,

Tendency to revert may die out with lapse of time, it is probable that the tendency to revert to the larger size would disappear: the race might then begin again to vary in the direction of smaller size; smaller individual dogs might be produced than any now in existence; and, if selection were applied to them, they would become the parents of a race of

and limit to variation may recede. dogs which would continually grow smaller, until the tendency to variation was once more checked by the tendency to reversion.

The reviewer shows that he is aware of this argument, but thinks that the assumption on which it rests—namely, that mere lapse of time will obliterate the tendency to reversion—is without any proof.

Of course direct proof is out of the question. Geology gives no evidence on such subjects; history is generally silent; tradition has forgotten them; and experiment is impossible in cases where an experiment might be only beginning to yield any

Reason of the possibility of this. result at the end of a thousand years. But I think it is as certain as such a thing can be, that all tendencies come under the laws of habit, and that all unused habits and unmanifested tendencies become weaker by mere lapse of time; though I admit we can scarcely ever be certain that the tendency to reversion has altogether died out.

CHAPTER XVIII.

DISTRIBUTION.

BEFORE we go any further in discussing the problem of the origin of species, it is necessary to consider the doctrine, which is chiefly associated with the great name of Cuvier, that all the facts of organization are to be directly referred to the conditions of that existence for which the organism has been created.

Cuvier's doctrine,

This brief and somewhat technical statement of the theory needs to be further explained. I have already defined organization as the adaptation of structure to function;[1] and I have stated the law of the physiological division of labour, which consists in setting apart particular tissues and organs for particular functions. Cuvier's doctrine is no more than an extension of this: it is, in truth, no mere theory, but a generalized statement of unquestionable and most important facts. He taught that every part of an organism[2] is directly and specially adapted to every other part, and all to the conditions of that existence for which it has been made; and this doctrine, so far from being in his hands a mere barren truism, enabled him, with the aid of his vast anatomical knowledge, to restore many extinct organisms, which were known only by a few fragments of bone: to restore them, I say, to the mind's eye and on paper, as an architect can restore a ruin. Thus,

of organic adaptation.

---

[1] P. 115.

[2] So far as I am aware, Cuvier made no attempt to apply this principle to vegetables; but no one who understands the rudiments of the subject can doubt that all such general principles are applicable to animals and vegetables alike.

for instance, carnivorous teeth are necessarily united with a carnivorous stomach; extremities modified for swimming, as in the seal or whale, are necessarily united with a form of body also suited for swimming. Such as these may be called functional adaptations. Besides these are what may be called structural adaptations: as, for instance, the adaptation of the form of the bones to the pressure of the muscles upon them; or the adaptation of the forms of all the organs in a serpent's body to the elongated form of its body. Functional and structural adaptations, of course, run into each other, and cannot be rigidly separated: the forms and characters of the various parts of an organism are determined by each other, and they are all collectively determined by the nature of the animal's life. Thus, a carnivorous life determines the existence of a carnivorous organization; a herbivorous life determines the existence of a herbivorous organization: so of a terrestrial or aquatic life, and of endless other classes of modifications.

Functional and structural adaptations.

The form of each part is determined by the rest, and all by the animal's life.

Concerning this doctrine, the question is not whether it is true; for there is no doubt whatever that every organ in an organism must be adapted to all the rest, and all to its mode of life: these truths are implied in all the facts of organization, and no fact of organization can be understood without bearing them in mind. The question is, whether Cuvier's doctrine *alone* will suffice to explain the facts of organization: whether the organization of a species can be referred to the conditions of its existence alone, or whether it is a resultant from the conditions of its existence jointly with some law, or principle, of a totally different and quite peculiar kind. Cuvier maintained the former: he always asserted that the whole organization of a species was directly referable to the conditions of its existence. But the necessity is now universally recognised of admitting a modifying principle of a distinct kind from this.

This is true:

but will it explain all the facts?

We must admit a further principle.

The two laws—for I admit them to be true, though I deny that they explain everything—the law, I say, that every part of an organism has its form and character deter-

mined by those of the other parts, and the law that the
form and character of the whole organism are determined
by the mode of its life, are inseparable from each other.
But, though logically in the closest connexion, they have
bearings on two very distinct parts of biological science.
The first—the law that the characters of all the parts are
mutually connected and mutually determined—has special
bearings on the problems of morphology ; the second—the
law that they are collectively determined by the mode of
its life—has special bearings on the problems of distri-
bution.　If those two laws were not only true, which they
are, but all-explaining, which they are not, all the facts
of morphology and distribution ought to be explicable by
them. The distribution and habitats of every species ought
to be explicable by the relation of its organization to its
mode of life ; and its morphology ought to be explicable
by the relation, both functional and structural, of its organs
to each other.　Now, is it so ?　These questions are, in
their nature, capable of being answered by an appeal to
facts.　I shall consider the facts of distribution first, not as
being the most important, but as being the simplest, and
the easiest to make intelligible.

　　It is to be observed, that even if Cuvier's doctrine were
all-explaining, it would not contradict the doctrine of the
modifiability of species; it would rather give support to
that doctrine ; because we know, from geological evidence,
that the physical circumstances of localities as to climate,
vegetation, &c. are subject to vast though slow changes ;
and if we believe that the characters of species are deter-
mined by the external conditions of their existence, it is a
reasonable inference that those characters may be modified
by a change in the conditions of existence.　But the
strongest evidence that we have of such changes in the
characters of species is afforded by facts that cannot be in
any sense referred to Cuvier's principle, though they are
quite consistent with it.

　　If Cuvier's doctrine, that the organization of an animal
is determined by the conditions and mode of its life, were

<div style="text-align: right">Bearings of
Cuvier's
doctrine
on mor-
phology
and on dis-
tribution.</div>

not only true, but true without any other modifying cause
—in other words, if organization depended on the con-
ditions and mode of life alone—it would be almost a
necessary inference, that if in any two regions the
conditions of life as to climate, food, and other external
circumstances are nearly similar, the organic populations
of the two ought also to be nearly similar; and the degree

External circumstances do not determine distribution. of similarity between the organic populations of any two
regions ought to be in some sort of proportion to the
similarity between the conditions of life in the two. But
there is no such relation—not even an approximation to it.
The degree of resemblance between the organic populations
of any two regions depends in scarcely any degree on the
similarity of climate and other conditions, but almost
entirely on their contiguity or distance, and the facility
with which they may have been colonised the one from
the other, or both from the same source. For instance,

Mountain species. mountain regions, when distant from each other, though
having similar climates, are not found to have similar
organic populations: on the contrary, the peculiar species
of each mountain region are, for the most part, nearly
related to the species inhabiting the neighbouring low
country, but modified, as if to suit the mountain life. The
inference is obvious, and I believe true, that the mountain
species are, not metaphorically, but literally kindred with
those of the plain: either the one group of species has
been descended from the other, or both have been descended
from the same source. I will mention another special and
very remarkable instance of the way in which species are
distributed. The three regions of Australia, South Africa,
and the southern part of South America are situated
between nearly the same parallels, and have nearly the
same climate (including, of course, in the word climate,
moisture as well as temperature); and climate is much
more important in determining the conditions of life than
all other influences put together. On the other hand,
the three old continents, Europe, Asia, and Africa, contain
every variety of climate, from the coldest to the hottest,
from the driest to the wettest. But Australia, South Africa,

and South America are separated, and probably have been
so for long geological ages, by wide, impassable oceans;
while the lands of Europe, Asia, and Africa are continuous,
and possibly have recently been more completely con-
tinuous than they are now. Accordingly we find, if we Distribu-
look to the distribution of the mammalia, that there is tion of mammalia
this strong resemblance between the zoological character in the old
of Europe, Asia, Africa, and also North America, notwith- continents,
standing their vast diversities of climate, that the most
conspicuous and characteristic mammalian order in them
all is that of the Ungulata, or hoofed animals. In Aus- Australia,
tralia, on the contrary, notwithstanding its similarity in
climate to that of South Africa, there is not a single indi-
genous Ungulate animal: all the indigenous mammalia
belong to the two orders which stand lowest in the class,
and are represented respectively by the kangaroo and the
ornithorhynchus.[1] The mammalia which are characteristic
of the southern part of South America, again, belong to South
the order Edentata, which are represented by the sloth and America, and
the armadillo, and are utterly unlike either the Ungulata
or the characteristic Australian orders. It belongs to this
class of facts, that Madagascar, notwithstanding its almost Madagas-
perfect similarity of climate to the neighbouring African car.
continent, has a totally different mammalian population,
chiefly consisting of lemurs, a tribe allied to the monkeys.[2] Wingless
And New Zealand has no indigenous mammalia at all, birds of New
their place being occupied by a remarkable tribe of wing- Zealand.
less birds.

The facts revealed in the recent geological history of
the same countries are equally remarkable and important.
Concerning Madagascar we have, I believe, no information
as yet about the remains of extinct animals; but in the Extinct
old continents, in Australia, and in South America, the animals of each
extinct mammalia of the geological periods nearest to the region re-
present were, in each region, generally of the same order, semble the living ones.

[1] The so-called wild dog of Australia is no real exception, as it is a half-
domestic animal with the native savages.

[2] See Dr. Sclater on the Mammals of Madagascar, Quarterly Journal of
Science, April 1864.

though different in species, from those which now inhabit the same region. The same is true of the wingless birds

Resemblance of species in conformable strata. of New Zealand. And it is a general fact in geology, that the fossil species of two strata, lying conformably one on the other, present a strong resemblance even where they are not identical. The inference is obvious, though I do not say certain, that when we thus find the same area to have been inhabited, in two successive geological periods, by similar though different species, the connexion between

Connexion by descent, them is that of descent. I say that, at the present stage of the argument, I do not regard this conclusion as proved. I believe I shall give ample proof of it before I have completed this work. I must, however, mention that when I speak of the newer set of species as connected with the older by the bond of descent, I do not mean direct descent like that by which we are connected with the races of men that inhabited the British Islands a thousand years ago : I

but modified. mean descent modified in a peculiar way, which I shall have to explain in another chapter.

But it may be urged, that Cuvier's principle of the perfect adaptation of the organism to the conditions of its existence may, after all, account for the facts of both the geographical and the geological distribution of species. It may be urged that we do not really know enough on the subject of the relation of the structure and characters of any species to the conditions of its life to assert that the one cannot be determined by the other. In a great variety of cases, the connexion is obvious enough ; as, for instance, in the adaptation of the monkey's hand or the woodpecker's foot to a life spent in climbing trees. But where the connexion is not obvious, we have no right to infer that it does not exist. The more we know concerning the subject of the complex relations between organisms and the conditions of their lives, the more intricate do these relations appear. Darwin has insisted on this with great force, and with all his accustomed lucidity.

I reply to this argument, that it is refuted by evidence identical in kind with the evidence of experiment. There are a great many instances of organisms being introduced

by the agency of man into countries to which they ~Foreign species gaining on native ones.~ were not native, and thriving so well in their new abode that they have gained on, and partly expelled, the indigenous species. Thus, European thistles and clover have covered great part of the Pampas of Buenos Ayres, and European clover and other plants are rapidly superseding the indigenous herbage of New Zealand.[1]

And there is evidence which, if possible, is still more direct and conclusive. No one can doubt the purpose of the webbed feet of water-fowl; yet there are geese that ~Upland goose.~ inhabit dry places, and make no use of their webbed feet. Nor can any one doubt that our woodpeckers' feet are ~Ground woodpecker.~ adapted to climb trees; yet there is a woodpecker inhabiting the Pampas of South America, where trees are unknown.[2] The inference is obvious, and I think certain, that the "upland geese" are a colony of geese which have abandoned an aquatic life; and that the woodpeckers of the Pampas are a colony of woodpeckers which have strayed away from their aboriginal forests, or perhaps have been expelled by the increase of some other species of animal that preyed on them. In both these cases the species have become modified in their new habitats.

Another most significant fact is, that small islands at a ~Bats on remote islands.~ distance from any continent usually contain no indigenous mammalia whatever, except bats, and many peculiar species of these are found on such islands. How have those species originated? The obvious answer is, that they are the descendants of bats that were once blown across the sea, and have become modified into new species in their new abodes.[3]

A fact which at first sight is not quite so intelligible is, ~Birds on the same, unable to fly.~ that among the small number of known species of landbirds that are unable to fly, a large proportion are found on islands. Thus, the Mauritius, before it was colonized by man, was inhabited by the dodo, an enormous sluggish ~The dodo.~ bird; and the neighbouring island of Rodriguez was inha-

1 Darwin's Origin of Species, p. 242.
2 Ibid. p. 212.   3 Ibid. p. 469.

bited by a bird, less sluggish than the dodo, but also
The solitaire. unable to fly, called the solitaire: these two species are
stated to be allied to the pigeons.[1]   But the most remark-
able group in the world of such birds is that which is now
becoming extinct in New Zealand.   These are not allied
to the pigeon, but are of the same order with the ostrich.
The dinornis. The extinct dinornis, the largest of all birds, was of this
family, which is now represented by the comparatively
The apteryx. small apteryx.   As indicated in the name of the apteryx,
these birds not only are unable to fly, but are without
external wings.   I believe the origin of these remarkable
species is to be accounted for in the same way as that of
the species of bats mentioned in the last paragraph.   It is
to be observed that the islands to which those birds belong
contain no native mammalia whatever, except, I suppose,
Origin of such races. bats.   The only assignable origin of those species of birds
is that they are descended from flying birds, which were
blown across the ocean long ages ago, and, finding the
country uninhabited, became the ancestors of birds which,
having plenty to eat and few enemies, in successive gene-
rations grew to an enormous size, and lost the power of
flight.   As the islands are without native mammalia,
they could have few if any enemies on the ground; and
if there were birds of prey, these could perhaps be best
eluded by keeping on the ground among the dense
vegetation of those islands, and not endeavouring to use
the power of flight.

Cuvier's principle will not explain the facts of distribu- tion. We may conclude, that although the principle of the
adaptation of every organic species to its mode of life, and
to the external conditions of its life, is generally true, and
of great importance, yet it utterly fails to account for the
facts of the geographical and geological distribution of
These facts support the theory of descent with modi- fication. species; while the facts of distribution give some support
to the theory of the origin of species by descent with
modification.   Especially is this true of the facts, that
geology shows the same area to have been usually inha-
bited during two successive geological periods by similar
though different species; and that geographical zoology

[1] See "The Dodo and its Kindred," by H. E. Strickland, F.G.S.

and botany show extensive contiguous areas to be usually
inhabited by similar though different species, even when
the climates of the two are very unlike.

In the next chapter I intend to consider how far the
facts of morphology can be referred to the principle of the
adaptation of every part of an organism to all the rest.

CHAPTER XIX.

MORPHOLOGY.

IN the last chapter the question was asked, whether the truth that every organism has been specially adapted to the conditions of its life will suffice to account for all the facts of the distribution of the various species of organisms through the regions they inhabit; and we have seen that although every organism is adapted to its habitat, yet this law of adaptation will not account for the facts of distribution. We have now to consider another and a parallel question.

We know that the form and structure of every organ in an organism is adapted to its function: thus, for instance, every carnivorous animal has carnivorous teeth. It neces-

Functional adaptations.

sarily follows from this, that the organs are all functionally adapted to each other: thus, every carnivorous animal has not only carnivorous teeth, but a carnivorous stomach, and such an organization of the muscles of the legs and jaws as enables it to seize, kill, and tear its prey. So that these three—teeth, digestive organs, and muscular organs—are each adapted to the carnivorous life, and to each other. And besides these purely functional adaptations, there are

Structural adaptations.

structural adaptations; such as—to mention what is, perhaps, the most obvious instance—the adaptation of the forms of the bones to the forms and pressures of the mus-

Is all morphology explicable by the law of adaptation?

cles. Now, the question we have to consider is, whether these laws of structural and functional adaptation will account for all the facts of morphology, or whether the morphology of any particular species is a resultant from

the law of adaptation, jointly with some other law of a
totally different and quite peculiar kind.

The law of adaptation may be briefly stated thus :— Statement
Every organ is adapted, structurally and functionally, to of that law.
all the rest; and the whole organism, and every organ in
it, is adapted to its mode of life.   This is true; every fact
of organic morphology is consistent with it, subject to
some small though remarkable exceptions, of which I shall
have to speak further on: but it is not true, as we shall
find, that every fact of morphology can be referred to
it alone.

Crystalline morphology and organic morphology are so Crystalline
remote from each other, that no analogical reasoning from morpho-
the one to the other can be in the slightest degree conclu- logy.
sive. But such analogies may be very suggestive. We have
seen that crystals of the same species are subject to great
variations in form, due to chemical differences in the medium
from which they have been formed; and that there is reason
to believe in similar variations among the lower species
of organisms, due to the soil, or medium, in which they
are developed. We know that in crystals, notwithstanding
the variability of form within the limits of the same species,
there are definite and very peculiar formative laws, which Formative
cannot possibly depend on anything like organic functions, crystalli-
because crystals have no such functions ; and it ought not zation
to surprise us if there are similar formative, or morpho- pendent
logical, laws among organisms, which, like the formative of func-
laws of crystallization, cannot be referred to any relation
of form or structure to function.   Especially, I think, is The same
this true of the lowest organisms, many of which show true, in
great beauty of form, of a kind that appears to be altogether part, of
due to symmetry of growth; as (to mention the best in- forms.
stance that occurs to me) [1] the beautiful star-like rayed

[1] I quote the following instance of the same kind of beauty resulting
from regularity, from the Duke of Argyll's " Reign of Law," pp. 199, 200 :
[The Diatomaceæ, a group of the lowest Algæ,] " have shells of pure silex,
and these, each after its own kind, are all covered with the most elaborate
ornament—striated, or fluted, or punctured, or dotted, in patterns which
are mere patterns, but patterns of perfect, and sometimes of most complex

Acantho-
metræ.

forms of the *Acanthometræ*, which are low animal organisms not very remote from the Foraminifera. These appear to consist of nothing but structureless sarcode, with a skeleton of siliceous spicules; they are allied to the *Thalassicollidæ*, of which, perhaps, they ought to be regarded as a genus. But the *Acanthometræ* are very much more definite in form than most of the *Thalassicollidæ;* yet this definiteness of form does not appear to be accompanied by any corresponding differentiation of function between different parts—or, in other words, by any physiological division of labour; and, so far as I can see, the beautiful regularity and symmetry of their radiated forms are altogether due to unknown laws of symmetry of growth, just like the equally beautiful and somewhat similar forms of the compound six-rayed, star-shaped crystals of snow.

Correla-
tions in all
organisms
not refer-
able to
adapta-
tion.

The adaptation of structure to function is the law, and indeed the definition, of organization; and the higher we ascend in the organic scale, the more definite and complete is this adaptation. But even in the very highest forms there are homologies and correlations which cannot be regarded as simply instances of adaptation. Before stating any of these, it is necessary to explain with more definiteness what is meant by homological relations. There are homologies between different species, and there are homologies within the limits of the same species. I shall consider first those which are within the limits of the same species.

Classes of
homo-
logies.

Of such homologies there are four distinct cases :—

1. Between different parts of the same organism;
2. Between the same organism at different stages of its development;
3. Between the sexes of the same species ; and
4. Between forms that mutually produce each other by metagenesis.

The first three cases occur among all organisms what-

beauty. . . . In the same drop of moisture there may be some dozen or twenty forms, each with its own distinctive pattern, yet all as constant as they are distinctive, yet having all the same habits, and without any perceptible difference of function."

ever, except those very low ones that have no distinction
of parts or of sexes. The fourth occurs only among com-
paratively low organisms. Among the higher organisms,
the different cases are perfectly distinct; but among vege-
table and comparatively low animal organisms, they gra-
duate into each other: indeed, where individuality is very
indefinite, it may be said that all the four are particular
cases of homology between parts of the same organism.

To make this last statement intelligible, it is necessary Homo-
logies of
the parts
of a tree in
flower.
to take an instance; and the most obvious and familiar
instance is that of a tree in flower. The tree at once bears
young buds and branches with fully developed leaves.
These may be regarded either as different parts of the
same organism, or as distinct organisms of the same
species in different stages of development. The tree also,
in most cases, bears flowers of both sexes; and if the male
elements are in one set of flowers and the female in
another (which is a very common arrangement), the two
sets of flowers may be regarded either as different organs
belonging to the same organism, or as distinct organisms of
the same species, but of opposite sexes.

Metagenesis, in the usual sense of the word, seldom Meta-
genesis of
Hydrozoa.
occurs among flowering plants, but it is common among
the Hydrozoa,[1] which, though unmistakeably animal, have
a very remarkable resemblance to plants, both in the way
in which single individuals or "morphological units"
are united into compound ones, and in the relation of
the generative organs to the whole compound organism.
Among some Hydrozoa the generative organs consist of
flower-like expansions, which never become detached from Flower-
like
organs.
the body of the Hydrozoon which has produced them, and
which are precisely analogous to flowers. But in other cases
these flower-like expansions acquire a mouth and tentacles
so as to be fitted for living alone. They then break off,
swim away, and in many cases grow many times larger
than the stock they have left, before they mature the gene-

---

[1] It is, I think, to be regretted that the unmeaning word hydrozoa has
been substituted for the beautiful and most appropriate word zoophytes,
or *animal plants*.

rative products. Such detached freely-swimming flowers of the Hydrozoa, as they may be called without metaphor, **Medusæ.** are known as Medusæ, or jelly-fish:[1] but it is a most important fact, to which we shall have to return again, that there are Medusæ which have not this origin. It will appear at least probable, after what has been said, that the freely-swimming Medusæ which are *detached from* some Hydrozoa are homologous with the flower-like organs that remain permanently *attached to* others: and what makes this probability a certainty is, that both have been observed in the same species. The reproductive organs in the same species have been observed in some cases to break off and swim away, while in other cases they grow, mature their products, and die like a flower, without quitting the parent stock. A clearer case could not be imagined of gradation between the production of a distinct organ, and the production of a distinct organism: for, according to any common and obvious use of words, the flower-like body is only an organ if it matures its products while in connexion with its parent organism, but is a distinct organism if it is detached; and yet the fact that the two cases occur in the same species conclusively proves that they cannot be fundamentally distinct.

In what sense metagenesis occurs in flowering plants. I have said that metagenesis does not usually occur among flowering plants. But if we are to regard, not the tree, but the product of each bud, as an individual, then metagenesis takes place in all trees whatever: the leaf-bearing branches give origin to flower-buds by non-sexual generation, and the flowers give origin by sexual generation to new leaf-bearing buds, which are developed out of their seeds.

Among the homological relations within the limits of the same species, there are many facts that cannot be accounted for by the principle of the adaptation o structures and functions to each other. To use a concise technical mode of expression; there are many *correlations* which are not *adaptations*. Thus the flower-like generative organs of the Hydrozoa are essentially

[1] It ought perhaps to be mentioned that Thalassicollidæ is *not* Greek for jelly-fish.

polypites, differing from the ordinary polypites very much Homo-
as flower-buds differ from leaf-buds.[1] (The polypite is the logies of
                                                             the parts
morphological unit of the Hydrozoon, as the leaf-bud of Hydro-
is of the tree.) And in those cases where the generative zoa :
organ breaks off and swims away as a Medusa, it still
continues to be essentially a polypite, though greatly
modified, and as it were disguised.

The relation between the leaf-buds and the flower-buds of flower-
of a tree is exactly the same as this. It is now universally ing plants.
recognised that the flower-bud does not fundamentally
differ from the leaf-bud; and that the flower consists of
parts which are essentially leaves, but modified to do
other work than that of the leaves.[2] Thus the calyx-leaves,
the petals, the stamens, and the pistils, are all homologous
with the leaves and with each other. This is shown by
the history of their development from the bud, and is
confirmed by the fact that in monstrous or abnormal
flowers they all graduate the one into the other. The best
instance with which I am acquainted of correlation be-
tween leaf-bearing and flower-bearing axes—that is to say,
between the products of leaf-buds and of flower-buds—is
that presented in the umbelliferous order, which have Umbelli-
somewhat feathery compound leaves, composed of small feræ.
leaflets, and small flowers clustered together into those
beautiful regular "umbels," from which the order has its
name. This resemblance between the manner in which
the leaves and the flowers are each combined is a corre-
lation which it seems quite impossible to refer to any
adaptation of structure to function. The function of the
leaves is to decompose carbonic acid and water, and to
form organic compounds ; the function of the flowers is to
mature the seed ; and there is no such connexion between
those two functions as to make it necessary or useful that

[1] This is proved, not only by their morphology, but by the fact that the
detached generative organs, or Medusæ, after maturing and parting with
the generative products, have been observed to root themselves and develop
into common polypites. (See the Rev. Thomas Hincks on the Development
of Zoophytes : Quarterly Journal of Science, July 1865, p. 416, note.)

[2] This is Goethe's well-known theory, awkwardly called the theory of
the metamorphosis of plants.

the leaves and flowers should be combined in the same
way. The resemblance between the form of the com-
pound leaf and of the umbel has, I believe, nothing to do
with their functions, and is comparable rather to those
laws of symmetry that govern crystalline form.

Their cor-relations not due to adapta-tion.

The resemblance, or difference, between flowers of op-
posite sexes is, of course, of exactly the same kind as the
resemblance or difference between flowers and leaf-bearing
axes. Both the sets of flowers consist of modified leaves; so
that, however different they may be, the difference cannot be
fundamental. The difference between the sexes among all
organisms that have the sexes on distinct individuals
appears to be of this kind. It is often very considerable
and most conspicuous, but never really fundamental. In-
deed, it is a remarkable fact that the secondary sexual
characters of any species are generally very variable as
between individuals of the species.[1] By secondary sexual
characters are meant those sexual characters which do not
belong to the sexual organs. I believe it may be added
that such characters usually appear comparatively late in
life. Thus, among the true insects, important as are the
wings for the purposes of their life, their presence or
absence is not a fundamental character, as is shown by
these three criteria, that they are never developed till long
after the insect has left the egg; that they are sometimes
present and sometimes absent in the same species;[2] and
that they are frequently a sexual character, being found on
the males only.

Differences of the sexes not funda-mental.

Secondary sexual characters are va-riable.

This general law, that the differences between the two
sexes of the same species are not such as to affect the
fundamental characters, is what might have been expected,
and it needs no special explanation. The same may be
said of the general law of metamorphosis, which is, that
the larva is formed on the same general type as the
perfect form, but is of a lower grade of organization. The
true insects are the highest of all articulated animals, and
the larvæ of those insects which undergo much metamor-

Metamor-phosis,

in insects,

[1] Darwin's Origin of Species, p. 184.
[2] This is the case among some beetles.

phosis resemble articulated animals of a lower organization : caterpillars resemble centipedes, and maggots resemble worms. The Batrachians (frogs, toads, and newts), which are the lowest air-breathing vertebrates, in their larva or tadpole state resemble some of the most lowly organized fishes, which are below the Batrachians in grade of organization. The crabs are the highest of the Crustacea, and their larvæ are unmistakeably crustacean, but crustacean of a lower grade. But the law that metamorphosis is accompanied by advance in grade of organization is only a general law, not a universal one. Among the Crustacea there are some remarkable exceptions to it; the largest of which, though not the only one, is that of the great order of Cirrhipedes, or Barnacles, which are decidedly crustacean, but in their mature state are metamorphosed into fixed animals covered with shells, and having so great a resemblance to the Mollusca that they were classed as such until their larval forms became known. This must be regarded as a case of retrograde metamorphosis, or metamorphosis to a lower type; for the larva, which has powers of sight and motion, is certainly a higher being than the mature animal, which has neither. Among the Echinoderms (star-fishes and sea-urchins) there are some very extraordinary larval forms, which have no resemblance whatever to the perfect form; but perhaps this exception to the usual law of metamorphosis is rather apparent than real. I shall have to speak of them in the chapter on Embryology.

We have seen that there are three cases of unlikeness of form within the limits of the same species. These are—

1. Between the larval and the mature forms ;
2. Between the sexes ; and
3. Between the forms that alternately produce each other by metagenesis. Under this last head, from a physiological point of view, comes, as we have seen, the relation between the leaf-bearing and the flower-bearing axes of plants.

In all these three cases, as a general rule, the differences are not fundamental: what may be called the ground-plan

[marginal notes:] Batrachians, and Crustacea. Cirrhipedes. Retrograde metamorphosis. Echinoderms. Resemblance between

the forms is the same, although there may be conspicuous external
of the same unlikeness, as there is between the maggot and the fly,
species. between the winged male and the wingless female of the
glow-worm, and between a flower and a leaf-bearing axis.[1]

We might This is what might be expected. We need not seek for
expect any special adaptation to purpose in the fundamental
this. resemblance between forms that belong to the same spe-
cies ; it would rather be necessary to seek for some special
purpose, if we found a fundamental difference.

There is, however, a well-known and remarkable in-
stance, and there are probably many others of the kind,
where the resemblance in external characters between the
sexes is carried further than is in any way needed by the
Nipples in purposes of life. I speak of the existence of nipples, which
man. are, in fact, rudimentary organs of lactation, in the male
of the human species. These have no function, and con-
sequently their existence cannot be referred to the law of
the adaptation of structure to function : it must be due to
a quite independent formative law.[2]

Relations The same is true of many of those relations of which I
of parts of have now to speak, between homologous parts of the same
the indi- individual, and even between parts which are not homo-
vidual. logous. Thus, the hands and the feet in man are evidently
Homology
of hands homologous, not only in their relation to the rest of the
and feet. skeleton, but in the number and position of the bones.
The resemblance is carried much further than the law of
adaptation to purpose will account for. That law will not
account for the fact that there are both five fingers and
five toes. If the hand needs five fingers for its uses, and
no more, the foot might surely have done perfectly well
Their with fewer than five toes. As I have mentioned in the
tendency chapter on Variation, the hands and the feet tend to vary
to vary
together, together : thus, persons with large hands usually have

[1] I say a leaf-bearing axis, not a leaf, because the flower consists of a
number of modified leaves, and consequently is homologous with an axis
bearing a number of leaves, not with a single leaf.

[2] A perfectly parallel case is that of the Hibernia leucophæaria, an
insect of which the male is winged, while the female is "nearly, though not
entirely apterous, the rudimentary wings being distinctly visible with a
good magnifier." (Mr. Inchbald, in the Zoologist, 1848, p. 2151.)

large feet, and the reverse; and they frequently present corresponding monstrosities. It seems impossible that this tendency of homologous parts to vary together can be in any way referable to the law of adaptation: I believe it has much more resemblance to the law, that the similar edges and angles of a crystal are similarly modified by the formation of secondary planes on them. In this case, as in that of the nipples, I do not say, nor do I believe, that there is anything inconsistent with the law of adaptation to purpose. I only say that there are relations which are not cases of that law, and are not to be explained by it. *like similar parts of crystals.*

But still more remarkable are the parallelisms between parts which are not homologous. Thus, none but ungulate or hoofed animals have horns, though horns are not found on all the Ungulata. It cannot be that no other animals have any need for them. Horns are weapons, to be used in fighting, and would have been in the highest degree useful to carnivorous animals, had they been endowed with them. The only reason, I think, that can be suggested why ungulates alone should have horns, is a reason that does not in any way come under the law of adaptation; it is, that they have a tendency to the production of horny matter, which appears in both the horns and the hoofs. I do not say that this conjecture is proved, or capable of proof; but it is supported by the fact that, when a tissue normally exists in one part of an organism, it is sometimes abnormally produced in another part, as for instance when the muscular walls of the heart are converted into a substance resembling bone. This, of course, occurs only in disease; but the tendency of the Ungulata to produce horny matter in their hoofs may in a somewhat similar manner determine its production in their horns. But, though the law of adaptation will not, I believe, account for the existence of horns on Ungulates only, it does account for their growing on the head, and not on any other part; for it is only there they could be useful. *Only ungulate animals have horns.* *Reason suggested.*

But there is, again, a remarkable fact concerning the position of horns on the head, which cannot, I think, be *Position of horns.*

brought under the law of adaptation. It is only Ungulates
with an even number of toes on the foot—that is to say,
cloven-footed animals—which have horns on each side of
the head. The only Ungulate with an odd number of toes
Rhino-
ceros.
that has a horn is the rhinoceros; and, instead of a horn
on each side of the head, he has one on its middle line, on
the snout. This coincidence is certainly remarkable. I
do not, however, lay much stress on it, because the peculiar
position of the horn of the rhinoceros may be an adapta-
tion to his muscular structure, enabling him to use his
weapon to the best advantage. But it is at least equally
probable that his muscular structure is adapted to the
position of the horn, and that the position of the horn is a
case of correlation between the head and the feet, and is
no more due to any adaptation of structure to function
than are the formative laws of crystallization.

Resem-
blances
of different
parts in
the same
organism.
It is very generally the case that different parts of the
same organism, even when not homologous, are formed in
much the same way. In other words, both the tissues and
the manner in which the tissues are combined into organs,
are alike in the different parts of the same organism. Thus,
Verte-
brata.
bone is peculiar to the Vertebrata, and is found both in the
spine and in the limbs; and the bones of both the spine
Articulata. and the limbs are covered by the muscles. In the Articu-
lata, which in many respects form a contrast and a kind of
inverted resemblance to the Vertebrata, the body is divided
into segments, and the limbs also are jointed; and in both
the body and the limbs the hard parts cover the muscles,
instead of being covered by them: so that the type of
their construction is opposite to that of similar parts in
Mollusca. the Vertebrata. In the Mollusca there is no skeleton at
all, with the single exception of the cartilaginous skull of
the cuttle-fish tribe (for the shell cannot be regarded as a
skeleton); the body is not segmented, and there are no
jointed limbs, only soft tentacles. Yet this is not con-
nected with any inferiority of organization, for the organs
of vegetative life among the Mollusca are very highly
organized; and the Cephalopoda (cuttle-fish and nautilus),
which are the highest Molluscan class, stand as high in

the animal scale as any of the Invertebrata. It belongs to
the same class of facts that the stem and the arms of the Crinoids.
Crinoids are jointed in a nearly similar way.

The conclusions arrived at in this chapter may be thus
summed up:—

All the facts of organic morphology are consistent with Summary
the adaptation of structure to function; but there are of facts.
many of the facts which are not cases of the law of
adaptation, and cannot be referred to it: such as (to
mention only a few examples) the resemblance, *in a
greater degree than is required by any purpose of adaptation*,
between the sexes of the human species, between homo-
logous parts like the hands and feet, and between the leaf-
bearing and the flower-bearing axes of the Umbelliferæ.

These are what Darwin calls correlations of form. It Correla-
ought not to surprise us to find this principle of correlation tion and
adaptation
pervading organic morphology. The wonder would be distinct.
rather if we did not find laws of the kind. But what I
wish to lay emphasis on is, that correlation in organic
morphology is totally distinct from adaptation to function,
and is much more nearly akin to the correlations of
crystalline morphology. No doubt a correlation of form
may serve a purpose. For instance, the correlation,
amounting to identity of form, between the external
organs on both sides of the body among nearly all the
Vertebrata and Articulata is much more convenient than
any unsymmetrical arrangement could be. But this will
not apply to the correlation between the hands and the
feet. The fact that the toes are the same in number as
the fingers, is, as I have endeavoured to show, a case of
pure correlation, which has nothing to do with adaptation.
If this appears doubtful, a proof of it, which may be
almost called an experimental proof, is afforded by the
fact that the hands and the feet habitually vary together,
and sometimes present similar monstrosities. These facts
can, I think, be only compared to the laws of crystalline Crystalline
morphology, that edges and angles which are similarly and or-
ganic mor-
related to similar axes are themselves similar; and that phology.
when the normal form of the crystalline species is modi-

fied, similar or homologous edges and angles are modified
alike. This last, as has been stated in the chapter on
Crystallization, is true not only of modifications that arise
spontaneously in the process of crystallization, but of
such modifications as are artificially produced by breaking
off an edge or an angle.

In this chapter we have considered only morphological
relations within the limits of the species. In the next we
are to extend our gaze over a much wider horizon, and
to consider the morphological relations between widely
separated groups,

NOTE.

Approach
to meta-
genesis in
Vallisneria
spiralis.

It has been stated (see p. 231) that metagenesis, like that of the
Hydrozoa, is rare among flowering plants. *Vallisneria spiralis*,
however, a plant which inhabits running streams, presents a case
somewhat similar to that described among the Hydrozoa. The
female flowers float on the water, like those of a water-lily : the
male flowers are matured below the surface, and when the pollen
is ripe they become detached, and float on the surface, where
they are carried by the current among the female ones.

CHAPTER XX.

COMPARATIVE MORPHOLOGY.

IN the last chapter we have come to a conclusion which
may be thus briefly recapitulated. Although the law
of the adaptation of every part of an organism to the rest,
and of the whole organism to its mode of life, is true; yet
there are many facts of the morphology of single species
which this law will not account for, and which point
rather to a principle of correlation of form, analogous to
the formative law of crystallization.

As yet I have spoken only of the morphology of
single species. It is obviously the logical order thus
to speak of the morphology of single species before the
comparative morphology of different species and classes;
for, were there only one organic species in existence—
whether man or the oak-tree, or any other species that has
a definite form—its morphology would be an object of
science; but it would be impossible to study the com-
parative morphology of different species and classes, without
basing the study on our knowledge of the morphology of
single species.

Having arrived at the above-stated conclusion with
respect to the principles of what may be called specific
morphology, we shall find the facts of comparative mor-
phology support that conclusion, and lead to other kindred
results.

It is necessary at the commencement to have a clear
conception of the difference between *analogical* relations
and *homological* relations. Two organs are analogous which
perform the same function: for instance, the wing of the

Specific morphology logically comes before comparative.

Analogy and homology.

R

Wing of bird and of insect.

bird and the wing of the insect are analogous, because they are both organs of flight; but they are not in any way homologous, because they have no resemblance either in anatomical structure, or in position relatively to the other organs of the body, or in the mode of their development. This is perhaps the best example that could be mentioned of two organs which are analogous without being homologous. Conversely, it is possible for two organs to be homologous without being analogous : perhaps the best instance

Lungs and swim-bladder.

of this is that of the lungs of the air-breathing Vertebrata, which are now universally believed to be homologous with the swim-bladder of the fish. This homology is made out, partly from the fact that the lungs and the swim-bladder are similarly placed with respect to the other organs of the body ; and partly from the existence of a tolerably perfect transitional series from fishes that have a swim-bladder to Batrachians (newts, frogs, &c.) that breathe by means of lungs, through the remarkable group of the Perennibranchiate Batrachians.

Homo-logies of respiratory organs variable.

This instance of the homology between swim-bladder and lungs introduces us to the fact, that the homologies of the respiratory organs of animals are peculiarly variable. This is not the case among the Vertebrata, except that the lungs of the air-breathing Vertebrata are not homologous with the branchiæ of fishes. And among air-breathing tribes of animals generally, the homologies of the respiratory organs are tolerably constant for each tribe. But among the water-breathing Invertebrata, the branchiæ are singularly inconstant, both as to their existence, and, where they exist, as to their position and homologies. I do not think this fact has received the attention it deserves. I shall have to recur to it as a most important one, and of great significance in accounting for that process of modification which, as I agree with Darwin in believing, has given origin to all organic forms.

Analogies and homo-logies within the species.

It is to be observed that what has been said about homologies and analogies between similar organs in different species is equally true of similar organs in the same individual. For instance, the fore-legs and hind-legs of a

quadruped are plainly not only analogous but homologous; they are analogous as to function, being all of them organs of support and motion; and they are homologous in their relation to the spine, and in the number and relative position of their constituent bones. In man, the arms are as plainly homologous in the same sense with the legs, both in their relation to the spine, and in the number and relative position of their constituent bones; indeed, as remarked in the last chapter, the resemblance of the hands and feet is carried much further than is demanded by any mechanical necessity. But the arms and the legs are not analogous with respect to function—in commoner language, they do different work. This, however, is not a very good example of the kind; for every man now and then uses his arms as legs. A much better example is that of the nippers of crabs and lobsters, which, like the arms of man, are evidently homologous with the legs, and yet are not capable of being used as legs. And the jaws of the Crustacea, and of all other Articulata, are homologous with their legs. This is made tolerably evident by the fact that, unlike the jaws of the Vertebrata, they open horizontally instead of vertically.

Legs and arms of Crustacea.

Jaws of Articulata.

Thus, organs belonging to the same individual may be homologous in position and structure without being analogous in function. The converse case is that of organs which are analogous in function without being homologous. The best instance I can remember of this is that of the fins of fishes. The pectoral pair and the ventral pair are homologous with each other, and homologous with the limbs of the higher Vertebrata. The caudal fin is, of course, not homologous with the pectoral and ventral fins; but it is homologous with the tail of the higher Vertebrata. And the dorsal fin is not homologous either with any other of the fish's fins, or with any organ whatever in any other vertebrate class.[1]

Fins of fishes.

---

[1] I believe the only organ in any other part of the animal kingdom that resembles the dorsal fin of the fish in position, is the so-called "foot" of the gasteropodous Mollusca, which in the Heteropoda is flattened into a vertical fin. This fin in the Heteropoda is ventral, not dorsal; but the ventral side in the Mollusca and Articulata corresponds to the dorsal side in the

It cannot in the least surprise us that organs, or sets of organs, like the pectoral and ventral fins, the caudal fin, and the dorsal fin, which are in no degree homologous as to their relation to the rest of the body, should be adapted for the same work of swimming, and for that purpose have received the same structure; being all formed of skin, supported and extended on a framework of bony rays. This is only a case of that adaptation which is the purpose of organization, and which we expect to find everywhere.

Homological resemblances carried further than necessary. But what really needs explanation is, that homological resemblances are in many cases carried much further than is needed for any adaptation to purpose. We have seen in the last chapter that this is the case within the limits of the same species; as, for instance, between the hands and the feet of the human species, and between the two sexes

Homological resemblances and adaptive differences. of the same. It is equally true, that between different species and groups there are homological resemblances of a degree and a kind for which no law of adaptation will account, though they are wonderfully harmonized with the law of adaptation. This is most evident among the Vertebrata, the general plan of which is much more constant than that of any of the lower groups, while it is equally susceptible of adaptive modifications for all possible kinds of life. This wonderful combination and harmony between homological resemblances and adaptive differences is best seen in tracing the homologies of the skeleton.

What I mean by the combination of homological resemblances with adaptive differences may, if the expression is not of itself intelligible, be understood by comparing the hands and the feet of man, which have the strongest homological resemblance, and yet are adapted for different functions—the feet for walking, and the hands for grasping.

Vertebrata, being the side where the nervous centres are. Huxley calls the side of the body which contains the nervous centres the neural side; that which contains the circulatory centre, or heart, the hæmal side. In the Vertebrata the neural side is the back, and the hæmal side the belly: in the Mollusca and Articulata, their relative positions are reversed. (Huxley on the Morphology of the Cephalous Mollusca, Philosophical Transactions, 1853.)

In a precisely similar manner, organs in different species, which are plainly homologous as to their position with respect to the rest of the body, and the number and relative position of their parts, are modified to serve totally unlike purposes in life. Thus, within the boundaries of the single class of the Mammalia, the hand of the man, the fore-foot of the dog, the wing of the bat, and the paddle of the whale, are all homologous; and not only homologous in position and in general relation to the spine and the rest of the skeleton, but down to the minutest detail: every bone in one has its homologous or corresponding bone in the others, though they are all variously modified in shape and size, to suit the purposes of the various modes of life of the animals to which they belong. Thus, if we would know all that is to' be known about the various forms of vertebrate skeleton, we must understand, not only the manner in which the skeleton of each species is modified in order to adapt it to its mode of life, but also the homological resemblances that underlie the adaptive modifications. To express the same by an example: if we would know all that is to be known about the man's hand and the bat's wing, we must understand the resemblance, amounting to identity, between the number and relative position of the bones of both, as well as the structural differences which adapt the hand for grasping and the wing for flight. The law of the adaptation of structure to function will not account for this homological resemblance—not only general, but in detail—between organs that are unlike in function. *Hand, foot, wing, and paddle, all homologous.*

Adaptation will not account for homology.

We see the same combination of two mutually modifying principles — morphological resemblance and adaptive difference—in comparing the vertebræ of different animals. Among fishes and serpents these are distinct, and jointed the one to the other, so as to be moveable. Among Mammalia and birds, some of the vertebræ continue to be moveable, but the form of the body, and the relation of the limbs to it, make it necessary for other vertebræ to be immoveably fastened together. Even when this is the case, however, they retain their visible distinctness as vertebræ; *Vertebræ separate in the lower Vertebrata, partly united in the higher.*

although the structure formed by their coalescence would be certainly as strong, and perhaps stronger, were it of a single bone, without any vestige of division into parts : at least, we know that in works of engineering it is always best, when it is practicable, to make any part where strength in a small compass is needed, out of a single piece. But even if there is no loss of strength, there cannot be any gain of it by retaining the visible distinctness of the vertebræ. This fact is consequently not explicable as a case of the adaptation of structure to function; and it is a very remarkable case of homological resemblance continued along with, and notwithstanding, adaptive difference.

How is homology to be explained ? How are we to explain these homological relations? Shall we be satisfied with the answer, that it has pleased the Creator to lay down a plan and keep to it ? This is true : generally true, though not, like the law of gravita-

Unity of plan is no explanation. tion, an invariable truth : but it is no explanation of the facts; it is only a generalized statement of them. Perhaps they are inexplicable, though I do not think so. I should not write as I do, were I not convinced that they are capable of explanation to a very great extent: but at least let us not advance that as an explanation which is no explanation at all. To say that the wonderful homologies of the vertebrate skeleton, to which I have little more than alluded, exist *because* the Creator has laid down a plan and adhered to it, is like saying that water rises in a pump *because* nature abhors a vacuum;—perfectly true as a statement of facts, ûtterly unmeaning if offered as an explanation of them.

No law subject to exceptions can be ultimate. Further, it is, I think, a true canon in the logic of science, that no law can be an ultimate one which is subject to limitations or exceptions. By an ultimate law, I mean one which is not resolvable into any other. Gravitation is such a law, and so, as I believe, are the elementary laws of Habit. But so is not the law that nature abhors a vacuum; and when it was experimentally ascertained that nature abhorred a vacuum to no greater height than about thirty-three feet, it became evident, at least to such sound thinkers as Galileo, that the abhorrence of a vacuum

could not be an ultimate law, but was one of which an explanation ought to be sought. Just so, the law of pre- Exceptions determined plan in morphology proves to be subject to ex- to plan. ceptions. I will mention one very remarkable instance. Nearly all the Mammalia have seven vertebræ in the neck, Cervical whether it is as long as in the giraffe, or as short as in the vertebræ of
Mammalia. whale. The only known exceptions to this are among the various species of sloth and of manati; and these two families, it is to be observed, belong to orders that have little else in common. In the manati genus, the usual number of cervical vertebræ is six: in the *Brachypus* genus of sloths, it varies from eight to ten: but in the *Cholœpus Hofmanni*, a species of sloth lately described by Professor Peters, it is only six.[1] Such an exception as this, in my opinion, goes very far to prove that the law of homology, or the law of adherence to types, is not an ultimate law, but one which is in its own nature capable of being explained by resolving it into simpler laws; even though the facts should prove to be too inaccessible, or too complex, to admit of its being so resolved by any science possible to man.

Such is the relation between the law of Homology and the law of Adaptation; so wonderful is the adherence to the minutest details of a type, while at the same time it is modified so as to make it perfectly adapted to the most different purposes (as in the case of the man's hand, the dog's foot, the bat's wing, and the whale's paddle); that it seems as if an intelligent power were adapting materials Intelligent given to it by an unintelligent one. And this, I believe, is and unin-
telligent no mere illustration, but the actual fact. The Intelligent powers. Power is that creative intelligence which, as I have already stated, I believe to direct the process of organic formation. The Unintelligent Power is the power of hereditary habit. I believe in the descent of all organisms from a few germs; I am still more strongly convinced of the descent of all organisms of the same type from the same ancestor; and as the vertebrate type is a very definitely marked one, I am fully convinced of the origin of all Vertebrates from a

[1] Quarterly Journal of Science, April 1865.

Homology due to common descent.

single ancestor. All those homological resemblances which are evidently not due to adaptation are in my belief due to community of descent. And those changes which are not due to adaptation, such as the abnormal number of cervical vertebræ in the sloth and the manati, are, I believe, cases of spontaneous variation.

Exceptions due to sponta- neous variation.

What is more than any other set of facts impossible to reconcile with the independent creation of every species, or indeed with any theory of the origin of species, except that of descent with modification, is the existence of rudi- mentary or aborted organs. To the fact of the existence of such organs I have alluded in a former chapter, as very remarkable exceptions to the general law that all structure is adapted to function. It is impossible to assign any function for such parts as the rudimentary toes of some Ungulata (hoofed animals), which appear as if they were made for no purpose except to complete the number to five, being the usual number of toes among quadrupeds; or for the rudimentary leg-bones of some serpents ; or for the rudimentary wing-bones of the apteryx, a bird of New Zealand, which has no external wings. The discovery of rudimentary organs occupies a similar place in the history and in the philosophy of biology that the discovery of the general prevalence of fossils occupies in the history and philosophy of geology. The old notion that the earth was at once created as we see it would be difficult enough to reconcile with the evident marks of aqueous and igneous action during past time ; but it became obviously un- tenable and absurd when it was discovered that the crust of the earth is full of the buried shells and bones of extinct races ; for it is impossible to believe that an Intel- ligent Creator would create dead shells and bones ; and, in my opinion, it is not less absurd to think that an Intel- ligent Creator would create animals with useless organs.[1]

Rudi- mentary organs.

Toes of Ungulata.

Leg-bones of serpents: wing- bones of apteryx.

Compa- rison of these to fossils.

[1] It has been suggested that the purpose of apparently useless parts may be similar to that of excretory organs, and may consist in disposing of useless matter. This, however, is totally inconsistent with the facts of the case. Phosphate of lime, which is the mineral constituent of bone, is not a material of which growing animals are likely to have too much. (See Darwin's Origin of Species, p. 538.)

The only real explanation ever given of their existence is, that they have been inherited from ancestors which had the same or homologous organs in a functionally active condition; that the leg-bones of serpents, for instance, are proof of their descent from animals that had legs, and the wing-bones of the apteryx are proof of its descent from a bird that had wings. The legs and wings of the ancestral forms have been lost as a result of that remarkable law in virtue of which a disused organ diminishes not only in strength but also in size.[1] Origin of these by descent.

Thus, though the law of adaptation is generally true, yet the existence of organs which are aborted, rudimentary, and useless, shows that it is subject to exceptions, and consequently is not a universal, ultimate, and all-explaining law. And though the law of homological parallelism—or, to use the common and very appropriate expression, the law of unity of type between organisms that are externally unlike—is generally true; as in the case already mentioned of the hand of the man, the fore-foot of the quadruped, the wing of the bat, and the paddle of the whale; yet the existence of such apparently capricious deviations from the type as that of the number of the cervical vertebræ in the sloth and the manati, shows that unity of type is not an ultimate and universal law. Exceptions to laws of adaptation
and of homology.

On the view of all organisms whatever *probably*, and *certainly* all organisms between which any unity of type is discernible, being descended from the same ancestor, the law of unity of type is fully explained. It is simply a case of hereditary habit. The fact of externally unlike organs, as alluded to in the last paragraph, being formed on what is fundamentally the same plan, is due to their being inherited from the same ancestor. But what needs further explanation, is the question how types have arisen and how they have been modified; how, for instance, and by what transitional stages, an original vitalized but unorganized germ has been modified into the fish, and the fish (which, as I shall show, is the original form of Unity of type, a result of community of descent.
Problem of origin and modification of types.

[1] Their disappearance is, however, in great part due to natural selection, of which I shall have to speak in a future chapter.

Vertebrates) into the reptile, the bird, and the mammal?
Of course, most of these questions cannot be answered
in detail. As already remarked, most of the transitional
forms have perished without leaving a ruin behind them.
But the laws of Habit are perfectly well known, and we
know something, though not much, of the laws of correla-
tion; and with the aid of these laws it is, I believe,
possible so to combine and co-ordinate the facts of em-
bryology and comparative morphology, that in some cases,
though not in all, we can arrive at definite, though general,
conclusions as to the stages of modification through which
organic forms have passed, and as to the causes and laws
which have determined the modifications.

How do we know that rudi- mentary organs are aborted, and not nascent? If this chapter is read by any intelligent man un-
acquainted with zoology, the question may probably occur
to him, by what criterion are we able to assert that the
leg-bones of serpents and the wing-bones of the apteryx
are proofs of descent from animals that had legs and
wings? Is it not as probable a conjecture that they are
remnants of the races from which the animals that have
legs and wings are descended? May not all birds be
descended from the apteryx tribe, and all air-breathing
Vertebrates from the serpents?

Classifica- tion. There are two answers to this question. The one is
based on the facts of classification. Serpents are not on
the *line of ascent* from fishes to the air-breathing Verte-
brata. The transition is not through the serpents, but
through the Batrachians (newts, &c.). And there is no
reason for thinking that the apteryx is on or near the
line of ascent from reptiles to birds. The ascent was, in
all probability, through the reptilian birds, the former
existence of which has been lately shown by geological
evidence.

But there is another answer, even more satisfactory than
this, inasmuch as it is independent of comparative mor-
phology, and depends only on the relation of structure to
function in the species. A serpent can never have given
origin to an animal with legs, or an apteryx to a bird with

wings, because the rudimentary bones in question are useless: in other words, they are not at work, and therefore are incapable of improving. Such organs as these, which have become rudimentary through disuse, are said to be *aborted.* But instances may be pointed out, of organs that are in the act of acquiring a new function; these may be called *nascent* organs for their new purpose. The best instance of this that I know of, is that of the lepidosiren, an animal concerning which it is a debated point whether it ought to be classed as a fish or a Batrachian, and which has its lungs in a state that presents an evident transition from the swim-bladder of a fish to the lungs of an air-breathing Vertebrate.

<div style="float:right">Organs if useless must be aborted.

Nascent lungs in lepido-siren.</div>

In this chapter I have endeavoured to show, that homological resemblances between organs which are unlike in form and function are explicable only on the supposition that they are proofs of a common descent. In the next, I intend to commence the attempt to explain, by means of the laws of habit and correlation, what the course of modification in certain cases has been.

CHAPTER XXI.

EMBRYOLOGY.

Develop-
ment is
from
simple
germs.

IN the chapter on Organic Development it has been stated that all development is from the simple to the complex. Every organism is developed from a simple structureless germ, and the germs and germinal matter of all organisms are in appearance exactly alike; there is no test, chemical or microscopic, by which the germ, or small mass of germinal matter, that is capable of developing into the highest Vertebrate can be distinguished from that which is capable of developing into a worm. Consequently, if it were possible to watch the development of a Vertebrate and of a worm, or of any other widely separated species of organisms, we should first see them perfectly similar, and afterwards see them becoming gradually more and more unlike, until their development was completed.

Species
become
unlike as
their germs
develop.

Develop-
ment is
differen-
tiation.

It has also been stated that development essentially consists in differentiation; that is to say, the process of development consists in the increasing unlikeness of tissues from each other, and the increasing separation of organs. When development is watched under the microscope (which can be done with many of those comparatively low animals that have bodies composed of transparent tissues, and with the eggs of fishes and frogs), the original structureless and homogeneous germ is seen to transform itself into different organs and tissues, each occupying its own part of the body of the developing organism.

From the truth that development consists in differentiation, it follows that the greatest differentiation is the highest development. Those organic species are the most

highly developed in which differentiation, that is to say the distinctness of the different organs and tissues, has been carried furthest; and those species are the lowest, or least developed, in which the original homogeneous germ has undergone the least differentiation, and remains most nearly in the original state. Consequently the undeveloped Embryos embryos of the higher forms bear some degree of resem- of higher forms blance to the mature states of the lower ones. That is to resemble say, an organism which has just begun a course of what is lower forms. destined to be very high development, has some resemblance to one which has completed a much lower course of development. This is a very general law, and it is, in a great variety of cases, carried out into a degree of detail that we could not have expected to find.

The germs of those organisms which have any decided Develop- structure do not at once begin to develop into the structure ment is indirect in which they are ultimately to attain. The germ at first most cases. acquires a simple cellular structure, and grows by the multiplication of its cells.[1] In this condition it resembles the mature states of the Protozoa and Protophyta (the simplest animals and plants, without any distinction of tissues except that of inside and outside of cell); and this cellular mass is afterwards transformed into the organs of the developing organism. Thus the process of development is seldom or never perfectly direct; that is to say, the germ does not at once begin to transform itself into the organism that is to be. In some groups it is much more direct than in others; and, on the whole, the lower the Generally organization the more nearly direct is the development: most nearly but this rule is subject to so many modifications and ex- direct in ceptions (due, as I believe, to causes that I shall endeavour groups. to set forth at the end of this chapter), that it cannot be stated as even an average or general truth. Among the Process lower aquatic Invertebrata generally, the germinal mass lower In- early loses its cellular structure (if indeed it ever possessed vertebrata.

[1] Carpenter's Human Physiology, p. 4, and Comparative Physiology, p. 176. All vegetable organisms, and the higher animal ones, appear to pass through this cellular stage of development, but it is certainly not proved of the lowest animals.

it) by the fusion of the cells into a mass of homogeneous and structureless but living sarcode, which is in fact germinal matter.[1] This sarcode mass swims about by means of cilia on its surface, and appears to perceive light and to avoid obstructions ; it almost exactly resembles one of the Protozoa, or animalcules. Within the sarcode mass the organs belonging to the organism at its next stage of development are gradually formed ; and when they are complete and ready for action, the sarcode is either gradually absorbed, which is the most usual case, or else cast off in mass.[2] This mode of development is indirect ; the Echinoderms, and the marine Mollusca and lower Annulosa, begin their life in the likeness of Protozoa, before they begin to transform themselves into their mature forms.[3]

They begin in the form of Protozoa.

The fact stated above, that the germs of the higher forms resemble the mature states of the lower ones, necessarily follows from the fact that the higher and the lower forms alike are differentiated out of perfectly simple germs, the higher ones being the most differentiated ; and these truths hold good in direct and indirect development alike. But more than this is true in indirect development. In the case of the aquatic Invertebrata just described, development begins and makes some progress on a plan of low organic type ; this plan is not continued but changed, and development begins anew on a higher type. Such change of plan during the course of development is very common among animals. In the cases just mentioned, the first plan of development is on the type of the Protozoa, which stands, as it were, at the base of the whole animal kingdom, and from which, on the theory of the origin of species by development, all

Change of plan in development.

---

[1] Dr. Wyville Thomson says of the embryos of the Echinoderms (starfish, sea-urchins, &c.): "After impregnation of the egg, and complete segmentation of the yelk, the whole germ-mass is resolved into an oval ciliated animalcule, composed throughout, and consisting entirely, of homogeneous structureless sarcode." (Natural History Review, July 1863.) I presume the "segmentation of the yelk" is an incipient formation of cells.   [2] See note at end of chapter.

[3] Dr. Wyville Thomson, in Natural History Review, October 1864.

the rest have originated; but where the higher forms of animals are developed by a similarly indirect process, their development, when the germinal mass first begins to differentiate into tissues, begins not on the plan of a Protozoon, but on that of a lower form of the same fundamental type to which the perfect form belongs.

This remarkable fact of a change in the plan of development is well known in particular cases, under the name of metamorphosis; the most familiar instance, and one of the best, is that of the transformation of the worm into the fly, or of the caterpillar into the butterfly. But metamorphosis is not confined to such obvious cases as these; it is universal among the air-breathing Vertebrata: in most of which, however, the metamorphoses are finished before the animal leaves the egg or the womb. All winged insects undergo metamorphosis, though some undergo much greater metamorphoses than others. Some leave the egg in the six-legged form of a mature insect, only without wings; others in a many-legged form like centipedes: these are the caterpillars. Others, again, leave the egg in the form of worms, without any legs, in which state they are called maggots. Now, insects are the highest class of the Articulata, centipedes are a lower class of that great group, and worms are a still lower class of the same than centipedes; so that the larval forms of insects resemble the mature forms of those lower classes to which they are allied. The same is true of the metamorphoses of the Batrachians (frogs, newts, &c.). These are air-breathing Vertebrates, and air-breathing organisms are, in general, higher than the water-breathing forms to which they are most nearly allied; but the larvæ, or tadpoles, of the Batrachians are water-breathers, and have branchiæ which are altogether homologous with those of fishes. The resemblance of tadpoles to fishes, however, is not to mature fishes, but to young or embryonic ones; and the same is true of insect larvæ: they do not resemble mature worms or centipedes, so much as immature ones.[1] To express this law in the most general terms:

Insect metamorphosis.

Metamorphosis before birth.

Insect larvæ resemble lower forms of Articulata.

So of Batrachia.

Larvæ resemble immature low forms.

[1] Carpenter's Comparative Physiology, p. 581.

when the original shapeless germinal mass begins to
assume the form of the species, it first assumes an em-
bryonic form, which is common to all organisms that are
constructed on the same general plan, whether that be
vertebrate, or articulate, or any other: it afterwards
assumes the definite form of its species; and the high-
est species, being the most differentiated, depart most
widely from the common embryonic form. Thus in-
sects, for instance, being higher than centipedes or
worms, depart more widely than do centipedes or worms
from the embryonic or larval form which is common
to all.

If the development theory of the origin of species is
true, there ought to be a perfect series of species present-
ing transitional forms between those lowest ones which
depart least in the course of their individual development
from the common embryonic form of the group, to those
highest ones which depart from it most widely. Between
worms and insects, most of the transitional forms appear to
be lost; but between fishes and the highest Batrachians
there is an almost unbroken series of intermediate forms.
Transition This series begins with the lepidosiren, an animal which
between is classed by Owen as a Batrachian, but by some naturalists
water- as a fish. The series is continued through the Perenni-
and air- branchiate Batrachians, a remarkable transitional order
breathing
Verte- which have two sets of respiratory organs : branchiæ like
brates. those of the fish for breathing water, and lungs like those
of the higher Vertebrata for breathing air. Next in the
series come the newts, toads, and frogs, which differ from
the Perennibranchiates in losing their branchiæ when their
development is completed, so as to become air-breathers
exclusively. And lastly comes the *Salamandra atra,* or
land salamander, which, like the higher Vertebrata, passes
through its metamorphoses in the egg, and leaves the egg
in the air-breathing form.

It is most important to observe, that there is a close
parallelism between the series of specific forms in the
Perennibranchiate order, and the series of forms through
which each individual among the higher or exclusively

air-breathing Batrachians passes in the course of its
ascending development.[1]

Another instance of the higher forms of a group passing
through stages of development similar to the mature
forms of the lower species of the same group, is afforded by
the branchiæ of the higher Crustacea, which in the course
of their development successively present the likeness of
the branchiæ of different inferior orders of the same class.[2]

Branchiæ of Crustacea.

But probably the most instructive, if not the most obvi-
ously interesting, of all cases of development, are those of
the Vertebrata.　I have spoken of the developmental
changes of the respiratory system in the Batrachians; and
there are facts in the development of the circulatory system
of the air-breathing Vertebrata which, we can scarcely
doubt, are profoundly connected with these.　It is obvious,
from the relation of respiration to the blood, that the posi-
tion of the respiratory organs, and of at least a portion of
the blood-vessels, must be determined the one by the
other.　The blood must flow where it will be aërated:
consequently, the plan of so much of the circulation as
ministers to respiration must of necessity be quite different
in the air-breathing Vertebrata from what it is in fishes.
But in the embryos of the air-breathing Vertebrata, the
blood-vessels are at first formed on the same plan as in
fishes: the blood flows towards that part of the body
where the fish's branchiæ are, and flows through arteries
which divide and reunite as the fish's branchial arteries
do; while slits are formed between the arterial branches,
like those which in many fishes admit the water into the
gills, although no branchiæ are ever formed.　At a later
period of development the plan of the circulation, so far
as it is connected with the respiratory organs, is totally
changed, and the "branchial slits" on each side of the
neck close up and disappear.[3]　Another closely-related fact
is, that bodies (the "Corpora Wolffiana") are formed in the

Circulation in vertebrate embryo.

---

[1] Carpenter's Comparative Physiology, p. 706.

[2] Milne-Edwards, quoted in Carpenter's Comparative Physiology,
p. 745.

[3] Carpenter's Human Physiology, p. 799.

S

Kidneys of
same.

embryos of mammalia and of birds, which are homo-logous with the kidneys of fishes. Unlike the branchial arteries, these perform their function at first : they act as kidneys until, before birth, they are superseded by the permanent kidneys.[1]

In the organs belonging to the nervous system, there is no case whatever, I believe, of any change in the plan of development : but, notwithstanding, the first embryonic brain of the highest animals is not a miniature likeness of

Brain of
human
embryo.

its mature state ; on the contrary, the human brain, when it can first be distinguished, is very like that of a fish ; but, in conformity with the law already mentioned, it is more like that of the embryonic fish than that of the mature one. And, as the successive stages of development in the higher Batrachians correspond to the ascending series of specific forms among the lower Batrachians, and as the successive stages of development in the branchiæ of the higher Crustacea correspond to the ascending series of forms among the lower Crustacea, so do the stages of the development of the human brain correspond to the brains of the ascending series of mammalian forms.[2] This kind of correspondence, indeed, is a general law. One of the

Develop-
ment of
spinal
column.

best instances of it is the development of the spinal column of Vertebrates, which begins in all as a mere tube of gelatinous substance, and afterwards becomes seg-mented : presenting successively, in the course of its development among the higher Vertebrata, the likeness of different forms which are those of mature forms among the inferior orders.[3]

Another instance may be mentioned, of what we may call physiological development, as distinguished from morpho-logical. Red blood-corpuscles are found in the Vertebrata only, and are all but universal in their mature forms :[4] but

[1] Carpenter's Human Physiology, p. 809.
[2] For these facts about the development of the brain, see ibid. p. 823.
[3] Carpenter's Comparative Physiology, p. 178.
[4] The only known exception is the amphioxus, which is the lowest of all fishes. It ought to be mentioned that some worms have red blood, but not red blood-corpuscles : the red colour is due to some diffused colouring matter.

besides the red corpuscles there are white ones, which are Blood-
corpuscles,
white and
red :
similar to those found in Invertebrates. In the develop-
ment of the vertebrate embryo the white corpuscles appear
earlier than the red; and it is now believed that through-
out life the red corpuscles continue to be formed by the
metamorphosis of the white. So that we have this re-
markable threefold relation between the two kinds: that their
threefold
relation.
the white are found in lower organic forms than the red;
the white appear in the embryo before the red; and the
white are transformed into the red throughout life.[1]

What inference are we to draw from these facts of in-
direct development? and especially from the resemblance
which we find to be so general, in various ways, through-
out the animal kingdom, between the embryo or larva of
the higher form, and the mature state of the kindred lower
form? How are we to interpret the facts, that the lower
aquatic Invertebrata usually begin their life in the likeness
of Protozoa; that the branchiæ of the higher Crustacea are
at first similar to those of the lower Crustacea; that many
insects leave the egg as worms; that the frog and newt
have the respiratory system of fishes, and consequently
their circulatory system also, before they acquire those of
air-breathers; and, most surprising of all, that the embryos
of the higher air-breathing Vertebrata at first develop
" branchial slits " and a branchial circulation like those of
fishes, with the arteries dividing as the arteries of fishes
divide?

It is a good rule, in all questions of this kind, to begin Can these
facts be
referred to
by trying whether the facts are capable of being all referred
to Cuvier's principle of the adaptation of every organ and the prin-
ciple of
every function in an organism to the rest, and of all to its adapta-
mode of life. But if it is difficult to apply this principle tion ?
with any precision to the morphology of organisms, it is
still more difficult to apply it to their development; if it
is difficult to be sure that we thoroughly understand the
purpose of any peculiarity of form or structure in the
organism considered simply as a living mechanism, it is
quite impossible to be sure that we understand all the

---

[1] Carpenter's Human Physiology, p. 168.

purposes for which one mode of development is better than
We do not another. We can see no purpose in indirect development;
know the
data for an for anything the wisest of us can see, the original struc-
answer. tureless germ of every organic species might as well have
developed into its mature form by the most direct process;
but we are so utterly ignorant of the conditions of the
problem, and any experimental test is so completely out
of the question, that it would be unwarrantable pre-
sumption in us to deny that there may possibly be as real
a purpose for the process of indirect development, as there
is for the process of circulation or of respiration. This, I
say, may be true, but all that can be said in its favour is,
that there is no evidence to disprove it: and it does not
appear probable. It appears very improbable, that a
change of plan while development is going on should be a
necessary law of development; it appears very much more
They are, likely, that the first transitory stage of an animal's develop-
more
probably, ment is a record, or, as it were, a picture, of what the mature
records of form of its remote ancestor was. I believe that the like-
ancestral
forms. ness of the earliest forms of the lower aquatic Invertebrata
to Protozoa is a record of their descent from Protozoa;
that the resemblance of the larvæ of many insects to
worms is a record of the descent of insects from worms;
that the resemblance of the branchiæ in the larval state of
the higher Crustacea to the branchiæ of the lower Crustacea
in their mature state is a record of the descent of the
higher Crustacea from the lower; and that the water-
breathing branchiæ of the tadpole are a record of the
descent of the frog from water-breathers.

As I have just stated it, I do not say that the argument
is conclusive. I think it is comparable to the argument
for the descent of all the Vertebrata from a common
ancestor, grounded on the homological correspondences
between their skeletons being so much closer than any
community of function requires. But the argument from
comparative morphology, which would have been otherwise
only a strong, though unverified, presumption, is raised, as
Useless I think, into a certainty by the discovery of rudimentary
organs,
and and useless members; which we cannot believe to have

been independently created, and which are explicable only as records of the descent of the organisms that possess them from ancestors to which they were of use. And here, in embryology, exactly the same confirmation comes in. There are not only useless organs, but useless modes of development, such as the formation in the embryos of air-breathing Vertebrates, of "branchial slits" and branchial circulation, which afterwards disappear and never perform any function. This is an exactly parallel case to that of rudimentary organs; and some of what are strictly rudimentary organs are found in embryos, and disappear before the organism comes to its mature state. Thus the embryo of the Greenland whale has teeth, which disappear by the time it is fully grown; the calf has certain teeth before birth which are afterwards absorbed;[1] and the young of some of the naked "nudibranchiate" Mollusca have discernible shells.[2] These, like the wing-bones of the wingless apteryx, are only intelligible as records of organs which were developed in the ancestors of those species, and were of use to them. It is also a significant fact, that rudimentary organs, even when they remain through life, are relatively smaller in the mature form than in the embryo;[3] this is no doubt a case of the law that unused organs diminish in size.

useless modes of development.

Rudimentary organs in the embryo only.

Rudimentary organs largest in the embryo.

As I have stated at the beginning of this chapter, all organisms are developed from germs which are perfectly alike; and they grow more and more unlike each other as their development proceeds. This may be called the differentiation of embryos one from the other. It is now time to state the law according to which that differentiation takes place.

Differentiation of embryos.

It is a familiar truth, that organic species are naturally arranged in groups, and these groups, again, in wider groups. Thus, for instance, the domestic fowl is one of the group of birds, and birds are a part of the wider group of Vertebrates. The law in question is, that as the deve-

Groups of groups.

---

[1] Darwin's Origin of Species, p. 534.

[2] Carpenter's Comparative Physiology, p. 318.

[3] Darwin's Origin of Species, p. 537.

Characters
of the
widest
group
appear
first.

Von Bär's
law.

lopment of any organism goes on, it acquires first the
characters belonging to the widest group in which it can
be classed, and afterwards acquires the characters of suc-
cessively narrower and narrower groups. This is known
as Von Bär's law. Stated in these general terms, it will
perhaps be scarcely intelligible, but an example will make
it easily understood. Were it possible to watch the de-
velopment of a chicken as it actually goes on in the egg,
we should see it first acquire those characters which it
has in common with all other Vertebrata ;[1] and it would
be capable of being identified as a vertebrate embryo,
before it could be known to which class of oviparous Verte-
brata it belonged. It would next be seen to acquire the
characters of a bird, without anything to enable us to
say what kind of bird ; afterwards it would acquire the
characters of the gallinaceous family of birds, and after
that, those of the domestic fowl ; last of all, the characters
that distinguish the variety or breed. And this differen-
tiating process does not stop at birth, for young animals
belonging to different breeds of the same species, or to
different species of the same genus, are generally—indeed
almost invariably—more nearly alike than are the mature
animals.

The characters of the widest group appear first—or,
what means the same, the characters that appear first are
those which the species has in common with the greatest
number of others ; and those which appear last are the
peculiar characters of the species—or, in variable species,
the peculiar characters of the variety or of the individual.
This is the statement of Von Bär's great and simple law.

[1] " In my possession are two little embryos in spirit, whose names I
have omitted to attach, and at present I am quite unable to say to what
class they belong. They may be lizards, or small birds, or very young
mammalia, so complete is the similarity in the mode of formation of the
head and trunk in these animals. The extremities, however, are still
absent in these embryos. But even if they had existed in the earliest
stage of their development, we should learn nothing ; for the feet of
lizards and mammals, the wings and feet of birds, no less than the hands
and feet of man, all arise from the same fundamental form." (Von Bär,
quoted in Darwin's Origin of Species, p. 519.)

This law stands in the closest connexion with that which we have seen to be a general law of comparative morphology: I mean that those characters which distin- Characters guish the widest groups are also the least liable to variation of widest groups are as between orders, genera, species, or individuals within the least group. The characters which appear first in the embryo variable. are those of the widest group, and the characters of the Connexion of this widest group are the least subject to variation. From with Von these two laws it follows, by syllogistic inference, that the Bär's law. characters which appear the earliest during development are the least subject to variation. The reason of this is tolerably evident. " If certain organs are formed early, Reason. those which come later must obviously accommodate them- selves to their predecessors ; and any variations which have taken place in the latter will perturb the normal disposition of the former." [1] Thus, the first-formed parts will vary only from such causes of variation as may arise in themselves; but the later-formed ones will vary, not only from such causes as may arise within themselves, but from any cause that may produce variation in their pre- decessors : so that the later any part is formed, the more chances it will have of varying. Whether this explanation is satisfactory or not, a good instance of the fact is pre- sented by the contrast between the development of the Mollusca on the one hand, and that of the Articulata and Vertebrata on the other. In the Articulata and Vertebrata, Mollusca, the neural side of the body, or that containing the nervous and Ver- centres, is developed before the hæmal side, or that con- tebrata. taining the circulatory centre ; and throughout those two great groups the general form of the nervous system is remarkably constant. In the Mollusca, on the contrary, the hæmal side is developed first, and the neural side after it ; and among them the plan of the nervous system is very much less constant. [2] The Mollusca present another remarkable instance of the same law. One of the most conspicuous and best-known molluscan characters is the very unsymmetrical form of their digestive organs, the

[1] Huxley on the Morphology of the Cephalous Mollusca, Philosophical Transactions, 1853.　　　　　　　　　　[2] Ibid.

Characters not embryonic are subject to exception. alimentary canal being doubled back so as to bring its two extremities near each other. But this character is not constant among the Mollusca : it is not found, for instance, among the chitons; and it is also not an embryonic character—on the contrary, the molluscan embryo is symmetrical, and the unsymmetrical form is subsequently produced by the right or left side, according to the species, growing more than the other.[1]

Unsymmetrical molluscan development.

Importance of embryonic characters in classification. The parts that appear the earliest are the most constant throughout wide groups. It is a result of this fact that the most important characters for classification are frequently those of the embryo or of the larva. It is usually said, development is the criterion of morphology; but it would, I think, be more intelligible to say that development is the criterion of classification : in other words, the history of the development of any organism is the test of its true affinities. The earliest developed characters are the fundamental ones, and true classification is classification by fundamental characters. The most remarkable instance of this is that of the Cirrhipedes, or barnacles; the position of which among animals was totally misunderstood so long as they were known in the mature state only. They were classed by Cuvier as Mollusca, which they resemble only in the possession of shells, and in other superficial characters; but now that their larval forms are found to be unmistakeably crustacean, they 'are classed among, or near, the Crustacea. Thus, of two crustaceans, which are at first almost alike,[2] one may end its life as a crustacean, while the other undergoes metamorphosis into the very different form of a cirrhipede. But this, though I believe it is by far the most remarkable instance of the kind, is not by any means the only one. A similar case exists among the marine worms. The dorsibranchiata and the tubicolœ are very unlike in external appearance : the former are free animals, with branchiæ in rows along the back; the latter are fixed animals, inhabiting tubular shells, with branchiæ round

Cirrhipedes :

their crustacean larvæ.

Dorsibranchiata, and tubicolæ.

[1] Huxley on the Morphology of the Cephalous Mollusca, Philosophical Transactions, 1853.

[2] Dr. Knox's translation of Milne-Edwards's Manual of Zoology, p. 448.

the head.   In some species these are magnificently deve-
loped, and, being filled with the creature's red blood, are
described as presenting the appearance of a carnation
flower.   Yet the young of the *tubicolæ* are almost exactly
like those of the *dorsibranchiata:* their subsequent unlike-
ness is due to their afterwards fixing themselves, forming a
shell, and developing branchiæ on the head.[1]

In a former chapter I have stated the fact of reversion, Reversion
that individuals are sometimes found which present what is some-
times
appears to be the character of the ancestral form from
which all the species of a genus, or, it may be, all the
genera of a class, are descended.   In this chapter we have
seen reasons for believing that the image of that ancestral
form is in some degree preserved in the embryo or larva.
Consequently, if development is arrested, if the embryonic the reten-
characters are in some degree retained, while the organism tion of
embryonic
in other respects becomes fit for mature life, there will be characters.
a reversion to ancestral characters.   In fewer words, re-
tention of embryonic characters is reversion to ancestral
characters.   This is beyond doubt the explanation of some
cases of reversion, though I do not say that it will apply
to all.   The best instance I know of is that of the flat-
fish or flounders, which differ from nearly all other verte- Flounders.
brates in their unsymmetrical form.   They habitually
swim with one side uppermost, and both their eyes are on
that side.   But this is true of their mature forms only.   Like
the Mollusca, they are symmetrically formed when in their
earliest state, and assume an unsymmetrical form in the
course of their subsequent development.   Young flounders
swim vertically, and have both sides alike, and one eye on
each side of the head, like fishes of the usual type.   And
fully-grown individuals are sometimes found among the
various species of the tribe which continue to swim ver-
tically, and have their two sides less unequally developed
than is usual among flounders.[2]   Considered in reference to

---

[1] Carpenter's Comparative Physiology, p. 369.

[2] See Dr. Wyville Thomson on the Obliquity of Flounders, Annals of
Natural History, May 1865.   He says of the wonderful change from the
young form, in which one eye is on each side, to the mature form, in which

the species only, these are monstrosities; but considered with reference to the type of the class, I have no doubt they are cases of reversion to it.

Funda-mental and adaptive characters.   The case of the flounders is a good instance of the difference between *fundamental* and *adaptive* characters. Embryonic characters, as we have seen, are fundamental. On the development theory of the origin of species, they are inherited from a very remote ancestry; and to the class of fundamental characters belong those homological resemblances, mentioned in the last chapter, between organs that are unlike in external form and in function, but present a minute resemblance in structure which cannot be accounted for by the law of adaptation of structure to function : such as the parallelism of formation between the hand of the man, the fore-foot of the quadruped, the wing of the bat, and the paddle of the whale. Adaptive characters, on the contrary, are acquired later in the course of development, and consist in modifications of the fundamental ones, so as to adapt them to the peculiar mode of life of the organism : such as the peculiar modifications of the common type, which fit the hand, the foot, the wing, and the paddle, each to its

Homology and analogy.   special function. Homologous parts are those which are developed in the same way, and their resemblance is consequently fundamental. When organs are analogous without being homologous, on the contrary, such as the wing of the bat and the wing of the insect, they are developed in different ways, and have no resemblance in their embryonic states. Their resemblance is acquired later, and is not fundamental, but only adaptive.

Homo-logical resem-blances are funda-mental.   To put the contrast in its sharpest form—when organs are homologous without being analogous, the resemblance is fundamental, and the difference is adaptive ; and the resemblance is greatest at first. Such are the man's hand and the bat's wing. When organs, on the contrary, are analogous without being homologous, the resemblance is

both eyes are on the same side : "The eye changes little in *actual* position : with the growth of the fish the associated parts are, as it were, *developed past it*, producing this singular obliquity."

adaptive and the difference fundamental; and there is no Analo-
resemblance at first.   Such are the bat's wing and the gical ones
insect's wing.   And similarly, though the wing of the bat adaptive. are
is precisely analogous with that of the bird, its homologies
are much nearer to those of the hand of man.

To return to the subject of the flounders.   We have Flounders.
seen that their peculiar unsymmetrical form is not an
embryonic character.   But it is plainly an adaptive one;
it is to be referred to their peculiar mode of life, requiring
them to be able to swim as close to the bottom as possible;
for which purpose they have acquired the habit of swim-
ming on one side instead of vertically, and have got their
forms modified to suit that habit.

Of course, the distinction between fundamental and
adaptive characters is not an absolute distinction, but
admits of gradations.   It is, however, generally true that
the fundamental characters are the embryonic ones; and
that those characters which appear first in the course of
development are the least variable as between individuals,
species, genera, and classes.   And if it is true, as is implied
in the development theory, that the most fundamental
characters are those which have been inherited from the Constancy
remotest ancestry, and through the greatest number of of funda-
mental
generations, it follows that the comparative invariability characters,
of fundamental characters is a case of that law of habit, a case of
the law of
in virtue of which the habits of the longest standing are habit.
the most tenacious and the least variable.

We have seen that nearly allied organisms undergo a
similar development; and that the characteristics of the
genus appear before those of the species, and the charac-
teristics of the wider group, generally, before those of the
narrower group.   These laws are subject to exceptions, Excep-
some of which are very difficult to explain; as when, in tions.
some cases, characters that belong to the species appear
earlier than others that belong to the genus.[1]   But there
is a large class of exceptions of a different kind, which,

[1] Stated on the authority of Agassiz, in Spencer's Principles of Biology,
vol. ii. p. 378.

when properly understood, will, I believe, be found not to disprove but to confirm the principles by which I have endeavoured to explain the laws; and at the same time to throw an important light on the origin of species.

When two organisms are developed from similar embryonic or larval forms, we infer that they are fundamentally alike; as in the case of the Cirrhipedes, which, as mentioned above, are now regarded as closely allied to the Crustacea, not from any likeness in their mature forms, but because they are developed from larvæ which are crustacean. It is indeed an axiom, that forms which are alike in their earliest stage of development are fundamentally alike, and are to be classed together. But the converse does not hold: organisms may be really allied, and yet may be developed out of very different larval forms. No one doubts, for instance, that the true or hexapod insects constitute a perfectly natural class; that is to say, a class whereof all the members have real and decided affinities to each other. Most of them leave the egg in a worm-like form; but "in some few cases, as that of Aphis, if we look to the admirable drawings by Professor Huxley of the development of this insect, we see hardly any trace of the vermiform stage."[1] And beetles constitute a perfectly natural order, yet some beetles are much more directly developed, and undergo much less metamorphosis, than others. Quite as remarkable is the case of the land salamander, which, unlike most of the higher Batrachians, does not pass through the tadpole stage, but leaves the egg as an air-breathing animal; yet we cannot doubt its affinity with the other salamanders, which begin their life as water-breathing tadpoles. Similar facts are observed among the Crustacea. "Fritz Müller has lately made the remarkable discovery that certain shrimp-like Crustaceans, allied to Penœus, first appear under the simple nauplius form, and passing through two or more zoea stages, and through the mysis stage, finally acquire their mature structure; now in the whole enormous malacostracan class, to which these crustaceans belong, no other

Likeness of larval form proves affinity: but not the converse.

Insects.

Beetles.

Land salamander.

Crustacea.

[1] Darwin's Origin of Species, p. 523.

member is yet known to be developed under the nauplius form, though very many appear as zoeas."[1] The Nauplius resembles the larva of the Cirrhipedes; and Darwin agrees with Fritz Müller that a similar form was the ancestor of the whole crustacean class.[2] It is another most remarkable fact, that the fresh-water Crustacea pass through no metamorphosis at all; their mature forms are developed directly from the egg.[3] I shall have to speak of the probable significance of this fact further on. *Fresh-water Crustacea undergo no metamorphosis.*

Supposing it to be true that the larva or embryo is a picture of what the ancestral form of the species was, these facts must be accounted for by supposing that there has been a substitution of direct development for indirect; or, in other words, that one or more stages of the process of development have been left out. I mean that, when a particular course of metamorphosis is characteristic of a class, but is not found in all the members of the class, it is most probable that those species which are developed directly without metamorphosis are descended from others which passed through the metamorphosis. Such a change is consistent with what we know of the laws of Habit. In the chapter on that subject we have seen that it is a common case for an inherited variation to appear in the offspring, not at birth, but at the same age at which it first appeared in the parent; but that it sometimes appears earlier in the offspring. Now, if it is true that the embryo is a picture of the ancestral form, and that the mature form is descended from an ancestor resembling the embryonic or larval one, it follows, to use Darwin's words, that "the adult differs from the embryo [or larva], owing to variations supervening at a not early age, and being inherited at a corresponding age."[4] But if, from some spontaneous variation, the offspring inherits and manifests the variation in question, not at the corresponding age but at birth, this will amount to leaving out the first *Direct development substituted for indirect.* *Laws of habit* *explaining metamorphosis,* *and the loss of metamorphosis.*

---

[1] Darwin's Origin of Species, p. 523.   [2] Ibid. p. 531.   [3] Ibid. p. 522.
[4] Ibid. p. 406. I make this quotation, not as a testimony to a fact, for this can be only matter of inference, but as showing that I agree with Darwin's opinion on this part of the question.

larval stage of development. For instance, the Batra-
chians are, I believe, descended from an ancestor resem-
bling a tadpole, which, from causes that I intend to speak of
in a future chapter, was transformed into an air-breathing
animal;[1] and in every successive generation the same
change takes place, and at about the same age at which
it took place in the original ancestor. But in the
land salamander the change into an air-breather is in-
herited, not at the corresponding age, but at birth ; and
thus it undergoes no metamorphosis. This account of the
matter is, I think, in accordance with what we know of
the laws of habit and variation, and of the facts of
embryology.

It is desirable, whenever it is possible, to adopt Darwin's
plan of reasoning from relations between varieties, the com-
mon origin of which is known, to relations between species,
the common origin of which can only be inferred ; and
Darwin has stated an instance in which the variations that
mark the several varieties of one species mostly appear some
time after birth, but in one variety are very conspicuous
at birth. "The young of the short-faced tumbler differs
from the young of the wild rock-pigeon and of the other
breeds in all its proportions, almost exactly as much as in
the adult state ;" while the young of the other breeds of
the pigeon, even of those which are most unlike in the
adult state, are very nearly alike.[2] The short-faced
tumbler, in presenting from the first the peculiar cha-
racters in which it differs from the original race of pigeons,
may be compared to the land salamander, which breathes
air from the first ; while the other varieties of pigeon, in
presenting at first the character of the original race, resem-
ble those Batrachians which commence their lives breathing
water, like the fishes from which they are descended.

To return to the subject of metamorphoses. We find in
nature the following series :—

*Batra-
chians.*

*Land sala-
mander.*

*Young
pigeons of
various
breeds.*

Series.

---

[1] I do not mean that this transformation took place in one generation.
On the contrary, I believe it must have occupied countless generations,
and must have passed through many specific forms, like those preserved
among the Perennibranchiates.

[2] Darwin's Origin of Species, p. 526.

1. Water-breathing Vertebrates (fishes) producing their Fishes.
like.

2. Water-breathing Vertebrates (tadpoles) developing Batra-
into air-breathers, which again produce water-breathing chians.
tadpoles from their eggs.

3. Air-breathing Vertebrates (the land salamander Air-
among Batrachians and all the higher vertebrate classes) breathing
producing their like. Verte-
brates.

I believe these three form a succession by descent in
the order enumerated; and I believe all the classes of
air-breathing Vertebrates have been in this way descended Descent of
from fishes, of which descent their embryos still bear the the latter
marks in the "branchial slits" of their arteries. fishes.

The existence of similar series in other parts of the Series.
animal kingdom is to be explained in the same way.
Thus we find this series :—

1. Worms producing worms. Worms.

2. Worm-like larvæ developing into hexapod insects, Insects
which again produce worm-like larvæ from their eggs. developed
from

3. Hexapod insects (as Aphis) producing hexapod insects, worm-like
which after they leave the egg undergo little or no meta- larvæ.
morphosis except the acquisition of wings. No insect, Insects
however, acquires wings until some time after it leaves directly
the egg. developed.

Among the higher, or malacostracan Crustacea, we find Crustacean
quite as remarkable a series, as follows :— series.

1. Nauplius producing its like. This, I believe, is Nauplius.
not known by direct evidence to exist or to have ever
existed; but we may infer its former existence from the
fact that "forms wonderfully distinct from each other, as
the suctorial parasites, Cirrhipedes, Entomostraca, and
even [a few of] the Malacostraca, appear in their first
larval state under a similar nauplius form."[1] From such a
Nauplius all those forms have probably been descended.

2. Nauplius developing into zoea, thence into mysis,
and thence into the mature malacostracan form of Penœus, Penœus.
or a genus allied thereto, which again produces Nauplii

[1] Darwin's Origin of Species, p. 531. Darwin agrees with Fritz Müller
in drawing these inferences.

from the egg. Of course it is not probable that the development of the Nauplius into any malacostracan form was effected in less than thousands, perhaps millions, of generations.

Other Malacostraca.

3. Malacostracans pursuing the same course of development as the Penœus, except that they leave out the nauplius stage and begin as zoeas.

Fresh-water Malacostraca have lost their metamorphoses by variation.

4. Fresh-water malacostracans developing by a direct process from the egg into the mature form.

The fact of the development of the fresh-water species being direct, is very significant. The fresh-waters have, it is tolerably certain, been colonized from the sea, and not the reverse : the change from salt to fresh water, like any other change, must have acted as a stimulus to variation ; and variation, among other modes of action, must have, in some cases at least, the effect of causing the young to acquire the characters of the parent at birth instead of by a subsequent metamorphosis.

Series in Hydrozoa.

I have kept the case of the Hydrozoa for the last. In it we have to speak, not of metamorphosis, but of metagenesis. In that class we find the following series :—

Hydra.

1. In the common fresh-water Hydra, the generative products are matured in organs which are mere swellings on the surface of the body.

Hydrozoa with flower-like generative organs.

2. In other members of the class the generative organs are distinct flower-like expansions. From the mere swellings of the Hydra to the flower-like organs of the campanularian and sertularian Hydrozoa, there is a regular gradation ; and the same anatomical elements are discernible through all the various forms of that gradation, much in the same way that the same anatomical elements are traceable through the various forms of the vertebrate skeleton.

Generative organs becoming detached as Medusæ.

3. In the forms just mentioned, the flower-like generative organs mature their products while in connexion with their parent stem, as do the flowers of plants. But in other nearly allied forms, the flower-like organs are detached before they arrive at maturity, and swim away. They grow to an enormous size in comparison with the

stock from which they have been detached, and are known as Medusæ, or jelly-fish. From the ova which they produce, animals are developed, like the parent stem, but unlike the Medusa: and these again produce Medusæ. So that we have this metagenesis, which is perhaps the most beautiful instance of the kind in the whole animal kingdom:— *Meta-genesis.*

A. Parent stem, comparable to the leaf-bearing trunk of a plant, producing Medusæ by a non-sexual process similar to the formation of buds by a plant.

B. Medusa, comparable to the flower of a plant, except that it is detached; producing, by a sexual process, ova that develop into the likeness of the parent stem.

There is no fundamental distinction between the species in which the flower-like organs mature their products while still in connexion with the parent stem, and those in which they become detached in the form of Medusæ. The two ways are observed in allied species; indeed they sometimes occur in the same species.

4. An instance has been observed in the genus Lizzia, and in all probability many more such instances yet remain to be discovered, of Medusæ being directly produced by a Medusa, without any metagenesis or metamorphosis.[1] *Medusa producing Medusæ directly.*

This series is evidently a similar one to those which I have traced through the Batrachians, the Insects, and the Crustaceans; and it is, to my mind at least, impossible to doubt that the members of this series, as of the others, have been descended each from the member enumerated before it.[2] *Parallel series.*

The conclusions arrived at in this chapter may be thus summed up:— *Summary.*

The embryonic or larval form of a species is most probably a record of what the ancestral form was from which the species has been derived.

---

[1] See Dr. Allman's Report on the Reproductive System in the Hydroida (Hydrozoa), British Association Reports, Newcastle, 1863.

[2] It is perhaps unlikely that the exact species from which any decidedly unlike species is descended can be still in existence; but very similar ones may be.

T

Nature of metamorphosis.

Metamorphosis is due to variations taking place not at an early age, and being inherited at a corresponding age in the offspring.[1]

How lost.

Metamorphosis, or metagenesis, may be lost by the characters of the mature form appearing at birth instead of some time after it. This is a very probable result of spontaneous variation; but the opposite change appears impossible. That is to say, it is a very probable variation for a species that has habitually undergone a metamorphosis, to acquire its mature form by direct development, and so to lose its metamorphosis; but it appears impossible that any species which has habitually acquired its mature form by direct development, should, as a result of any variation, begin to appear first in a larval form. I deduce this from the law of habit, that an inherited character sometimes appears in the offspring at the same age as that at which it appeared in the parent; sometimes earlier, but seldom or never later.

If any one, previously unacquainted with the subject, considers and compares the facts that have been brought together in this chapter, he may very probably make some comment like this: " A plausible explanation is here

---

[1] This does not apply to metagenesis. But metagenesis, though a less familiar fact than metamorphosis, is not nearly so difficult to account for. Such metagenesis as that of Aphis or of Cecidomyia (a dipterous insect) consists in the generation of larvæ by the larva, and needs no special explanation : what does need explanation is the metamorphosis of the larva into the perfect form, which, in Aphis at least, always occurs at intervals of a few generations. Such metagenesis as that of the Hydrozoa consists in the reproductive organs becoming detached, which may take place as the result of a very slight variation.

In metamorphosis, form *A is transformed into* form *B* (as the caterpillar into the butterfly), and form *B produces* form *A* again. In metagenesis, form *A produces* form *B*, and form *B produces* form *A* again, as in the case of the hydra-like Hydrozoon and its Medusa. In Aphis, the two processes are complicated together. Larvæ produce larvæ for several generations, and perish without undergoing metamorphosis; but at intervals they are metamorphosed into the winged state, and a new generation of larvæ is produced from their eggs. This is classed as a case of metagenesis, because there is one form in the cycle that remains permanently unlike the other : the larva that dies without undergoing metamorphosis never becomes like the winged form.

offered of the manner in which stages of development
have been dropped out, and the process of development
thereby shortened.   But this is no explanation of the Objection.
Origin of Species.   The difficulty is not to know how
metamorphosis and metagenesis have been suppressed, but
how they began.   You tell us how the land salamander[1]
has ceased to begin life as a tadpole : but how did the
first salamander make the transformation from a water-
breathing tadpole into an air-breather ?   You tell us how
the Aphis has ceased to appear as a worm; but how was
the first worm transformed into a hexapod insect ?   You
tell us how the fresh-water Crustacea have ceased to leave
the egg as zoeas; but what determined the first transfor-
mation of a zoea into a crayfish ?   You tell us how the
Lizzia form of Medusa has come to produce its like with-
out alternating with a hydra-like form; but how did the
first hydra-like form begin to throw off Medusæ ?   Until
these questions, and such as these, can be answered, the
mystery is unsolved."

  I admit that what I have said leaves altogether unsolved Reply.
the mystery of the origin of organic forms.   I intend, in a
future chapter, to show how far I think that mystery is
capable of solution.   But I cannot admit that we know
nothing in any case where we are unable to ascend to
a knowledge of causes.   A true and correctly generalized
view of facts not only is valuable in itself, but is often the
means by which it becomes possible to ascend to the
knowledge of causes.   The discovery of Kepler's laws is
justly regarded as one of the most important contributions
ever made to science, though Kepler died in ignorance of
the reasons of those laws; but Kepler's discoveries pre-
pared the way for Newton's discovery of the law of gravi-
tation, which has explained the reason, not only of Kepler's
laws, but of the apparent exceptions to them.

  But before going on to the subject of the causes of these
transformations, I shall endeavour to show how the deve-
lopment theory of the origin of species agrees with the
facts of classification.

  [1] *Salamandra atra,* or land-newt.

NOTE.

ANOMALIES OF DEVELOPMENT.

ALTHOUGH I am convinced of the truth of the principles set
forth in the foregoing chapter, I admit that there are facts of
development and metamorphosis for which I am utterly unable
to suggest any way of accounting. One of these is that of the
Sitaris beetle, which, when hatched, has six legs like a mature
insect : these afterwards become rudimentary, and it assumes
the ordinary form of a worm-like larva, and is transformed into
a beetle in the usual way.[1]

Metamor-
phosis of
Sitaris.

The development of some of the Echinodermata cannot·be
called an exception to the ordinary laws of metamorphosis only
because it lies altogether outside of them.[2] As already stated,
the aquatic Invertebrata are usually developed out of a germ
which is nothing but a minute mass of structureless sarcode,
bearing cilia on its surface, by means of which it swims about.
Dr. Thomson calls this the pseudembryo : perhaps pre-embryo
would be a better word. Within it the true embryo is afterwards
developed ; and in most cases the external ciliated " sarcode
layer" is absorbed by the developing embryo, and disappears.
The peculiarity of some Echinoderms is, that the pseudembryo
undergoes a development of its own, which has no morphological
relation to that of the future animal. Its form varies greatly in
different species. In some it is described as " vermiform ;" in
the sea-urchin and star-fish it appears more like the Ciliograda
than any other form.[3] The difference between a larva and a

Develop-
ment of
Echino-
derms.

Pseud-
embryo.

[1] Stated on the authority of M. Fabre, in Darwin's Origin of Species,
p. 530.

[2] The facts in this paragraph are taken from Dr. Wyville Thomson's
papers in the Natural History Review for July 1863 and October 1864.

[3] Professor Sars, who discovered the Bipinnaria, or pseudembryo of the
star-fish, before he knew what it was, thought it might be allied to the
Ciliograda. The resemblance in external form of Dr. Thomson's figures
of the various Echinus or Sea-urchin pseudembryos to the Ciliograda is,
I think, obvious enough.

pseudembryo is, that the larva is transformed into the mature
form, but the pseudembryo is not so transformed; its substance
is in most cases absorbed by the growing embryo: there is thus
a transformation of the substance, but this is not as the sub-
stance of a larva is transformed into that of the perfect form; it
is rather as food is transformed into the substance of the
organism. But the pseudembryo of the star-fish, instead of being Pecu-
absorbed, is cast off, and continues to live for some days. liarity of that of
Dr. Thomson quotes Dr. Carpenter's remark, that the structures the star-
first developed in the egg of the bird hold nearly the same fish.
relation to the rudimentary chick that the pluteus (pseudembryo)
bears to the incipient Echinus or Ophiura, or the Bipinnaria
to the incipient star-fish.

There are also these distinctions between pseudembryos and Pseudem-
ordinary larvæ:—In the cases now under consideration, deve- bryos and larvæ.
lopment is *not* the criterion of morphology, nor of the true
affinities of the species; on the contrary, the pseudembryonic
forms are much less constant throughout the class than the
mature ones; and, unlike what we find in metamorphosis and
metagenesis, there is no morphological resemblance whatever
between the pseudembryonic and the mature forms of the Echi-
nodermata. A tadpole and a frog are both Vertebrates; a maggot
and a fly are both annulose animals; a zoea and a crab are both
Crustaceans; and a Medusa is morphologically a hydrozoon,
though externally much modified; but a pluteus or a bipinnaria
is not in the least like an echinoderm. For these reasons I do
not think it likely, or even possible, that the ancestors of the
Echinodermata are in any way represented by their present
pseudembryos. I am at a loss even to guess how this extra-
ordinary mode of development can have originated.

CHAPTER XXII.

CLASSIFICATION.

Classifica-
tion
depends
on Embry-
ology.
   THE subject of classification is much more familiar than that of embryology, and, apparently, has to do with much more obvious facts. Nevertheless, classification as now understood depends on embryology; for which reason I have treated of embryology first.

What is
meant by
the facts of
classifica-
tion.
   At the end of the last chapter I used an expression which to many may appear strange. I spoke of the *facts of classification*. It may be asked: "What does this expression mean? What is classification but an affair of words and names? What other merit can the best classification have, than that of being the most convenient?"

Questions
of classifi-
cation are
real.
   I have in a former chapter[1] stated my conviction, which is that of most if not all men who have given any attention and thought to the classificatory sciences, that there is not only a distinction in classification of convenient or inconvenient, but also a distinction of true or false. It is perhaps difficult to prove this to the satisfaction of any one who has not a general familiarity with the outlines of those sciences; for such a conclusion is not like a mathematically demonstrated proposition, which is necessarily assented to as soon as the reasoning is understood on which it rests; on the contrary, the general conclusions of biological science mostly depend on cumulative evidence derived from a variety of facts of various kinds, and of very different degrees of importance.

Before going on with the subject of this chapter, I wish
to remove a possible source of confusion. I have stated
that questions of classification are not mere questions of
words and names, but have to do with realities.   Thus
the assertions that the whale is not a fish, but a mammal
having the external form of a fish, and that a cirrhipede is
not a molluscan, but a crustacean which has put on the
form of a molluscan, are assertions not merely concerning
the names which naturalists have agreed to use, but con-
cerning the real nature and affinities of those animals.
These are cases of members of one group being disguised
in the likeness of another, and in such cases we know
nothing unless we know the real affinities of the species
under review, and consequently its true classification. But Questions
there are other questions of classification which are little of classifi-
more than questions of words.   It is, for instance, very which are
difficult to say where the series of fishes ends, and that of merely
Perennibranchiate Batrachians begins; it is very difficult verbal.
to say whether the lepidosiren is a fish or a Batrachian. Position of
But it is as needless as it is difficult to decide such a lepido-
question.   The two groups run into each other, and there siren.
is so complete a gradation of intermediate forms, that the
line can scarcely be drawn between them except arbitrarily.
It is scarcely a metaphor to say that the lepidosiren is a
fish which we have caught in the act of acquiring lungs and
transforming itself into a Batrachian.   But Mammalia and
fishes, or Crustacea and Mollusca, are not groups that run
into each other; the whale has no tendency to become a
fish, nor has the cirrhipede any tendency to become a
molluscan.

It needs no proof that the value in classification of any The value
character depends, not on the importance of that character of any
to the life of the organism, but altogether on the extent in classifi-
to which it is so correlated with other characters as to be cation
an index to the general nature and affinities of the on being
organism.   Thus, on the one hand, as I have mentioned to others.
already, the presence or absence of wings in some groups
of beetles is very inconstant, both as between otherwise
similar species and between individuals of the same species ;

Value in classification of rudimentary organs,

while, on the other hand, organs which have become rudimentary, and therefore useless, like the nails under the skin of the manati (an aquatic mammal), are regarded by the best authorities as of importance at least equal to that of organs homologous with them, but in a state of func

and of organs not connected with special habits.

tional perfection and activity. " It may even be given as a general rule, that the less any part of the organization is connected with special habits, the more important it becomes for classification." [1] " With plants, how remarkable it is that the organs of vegetation, on which their whole life depends, are of little signification excepting in [separating the whole vegetable kingdom into] the first main divisions; whereas the organs of reproduction, with their product the seed, are of paramount importance." [2]

If we believe in the theory of the origin of species by development—or, to use more accurate language, if we believe that different species have been derived from a common ancestor by descent with different modifications— all this, and much more, at once becomes intelligible.

The development theory explains all this.

Before the " development theory " became familiar to scientific men, and while the origin of species was regarded as something inscrutable, like the origin of matter or of life, though naturalists were instinctively certain that their words had a true and important meaning when they spoke of *true* classification and of *real* affinities, yet they found it impossible to state what that meaning was, in a way that was satisfactory even to themselves. But if the development theory is true, real affinity simply means affinity of kindred by descent, and true classification is by

Affinity means kindred; as of Cirrhipedes to Crustaceans.

genealogy. When we say, for instance, that the Cirrhipedes, or Barnacles, though totally unlike in form and appearance, are proved by the character of their larvæ to be closely connected with the Crustacea, what we mean is, that they are literally akin to the Crustacea, being descended from crustacean ancestors. Not only every species but every

Groups within groups.

genus is descended from a single ancestor; all the genera of an order are descended from a single ancestor further back; so of all the orders of the same class, and all the

---

[1] Darwin's Origin of Species, p. 489.   [2] Ibid. p. 490.

classes of the same great division, such as the Vertebrata. Thus far, I believe the development theory is as completely proved as any truth can be, of which we have neither direct evidence nor mathematical demonstration.   More than this I do not think we are yet in a position to assert with the same confidence; but I believe that all organisms whatever are descended from a common origin.   It will be seen why, on this view, so much importance in classification should be attached to organs that have become rudimentary and aborted; for they show the descent of the organism as clearly as if they were conspicuous and at work.   It will also be seen why the highest importance in classification is attached to those organs which are earliest formed in the embryo, and to embryonic characters generally; for the first developed characters, as shown in the last chapter, are the least variable, and have probably varied the least throughout an indefinite number of generations.   And it will be seen that although the flower and the seed-vessel in plants are not developed early, yet they are of high classificatory importance for the same reason that embryonic characters are; namely, that they are unlikely to be greatly changed by any change of an adaptive nature.   Adaptation to a new habitat, for instance, or change of climate, will be much more likely to change its habit and mode of growth—to make the difference, for instance, between a tree and a herb—than to make any great change in the character of the flower.

How far the development theory is proved.

Reason of importance of rudimentary organs:

of embryonic characters:

of the flower.

The foregoing remarks will all be familiar to the student of Darwin.   What follows is not absolutely original; but it has not yet, I think, been stated with the emphasis it deserves.

We suppose the following to be the *rationale* of the facts of classification :—

All living beings have a capacity for variation, which is very limited in a single generation, but (like geological change) quite unlimited if sufficient time is allowed, so that the variations of successive generations may be added

Origin of organic forms by the accumulation of variations.

together. All organic forms have come into existence by the accumulation of such variations, ever since they began in those first vitalized but unorganized germs from which I believe all organisms to be descended. Different forms have come into existence by the accumulation of different

Divergent lines of variation.

Divergence and re-divergence.

Classification is genealogy.

sets of variations along different and diverging lines of descent; and these lines ever diverge and re-diverge—that is to say, forms ever become differentiated and re-differentiated from each other—giving origin to subordinate groups. Thus the true classification, could we find it, would be a genealogical table; and the best attainable classification is that which most nearly approximates to genealogical affinities.

In the genealogical table of a human family, if it represents the whole of the family, and not the leading branch only, there are such diverging and re-diverging lines of descent. In the human genealogy, however, lines that have diverged may reunite by the intermarriage of cousins; and thus a new line may arise, mixing the blood, and probably combining the characters, of the two

No re-union after divergence.

parent lines. But in the organic genealogy such unions are impossible; for organisms cannot produce offspring together after they have diverged into decidedly different forms. In our organic genealogical tree, consequently, the branches, which are classes, should never reunite after diverging.

Metamorphosis generally is progress.

Further, the facts of metamorphosis, as stated in the last chapter, go to prove that when any important change takes place it is generally towards a higher form. The frog is higher than the tadpole, the butterfly is higher than the caterpillar, and the crab is higher than the zoea; and

Exception in Cirrhipedes.

Specific change also is generally progress.

though the cirrhipede is not higher than its nauplius-like larva, this case is exceptional. And if it is true, as I have shown reason for believing, that the ancestral forms from which the *species* of these groups have been developed resembled the larvæ from which the *individuals* are still developed, then the direction of change of species, as well as of metamorphosis of the individual, is in general, though not invariably, towards higher forms.

Thus the branches of our symbolical organic tree should *never reunite* after dividing, and should *generally ascend.* Do the facts support these *à priori* conclusions ?

So far as the facts are known they do. It is a familiar remark to naturalists that groups are united by their lower rather than by their higher members. Were this universally true, it is obvious that the organic tree would have its branches always ascending and never reuniting. This is a subject of great importance, and I must illustrate it further. The organic tree consists of two main trunks, the vegetable and the animal. It is by the lowest members of both groups that they are brought into contact. There are many forms concerning which it is uncertain whether they are animal or vegetable ; and perhaps, indeed, we make ourselves the slaves of our own words when we assume that every organism must be definitely either the one or the other. The sarcode of which the bodies of the Protozoa are composed does not appear essentially to differ from the protoplasm contained in vegetable cells ; and if it is true, as I think most probable, that this community of properties indicates community of origin, the germ, or germs, from which both the vegetable and animal kingdoms have been descended, must have been neither decidedly vegetable nor decidedly animal, but capable of acquiring the properties of either.

Groups are generally united by their lower members.

Animal and vegetable kingdoms.

Their probable common origin.

This is perhaps the best of all the many instances which might be enumerated of the general law that groups are united by their lowest members, and separated in their higher forms. We have seen that it is nearly impossible —I am inclined to think quite impossible—to make any absolute distinction between the lowest plants and the lowest animals. But between their highest forms the distinction is not only fundamental, but is also so obvious that it cannot be mistaken. The warm-blooded Vertebrata are the highest of all animals; and, though there is no vegetable class that stands so decidedly at the head of that kingdom, we cannot be far wrong if we regard the Rosaceæ and their allies as the most highly organized

No absolute distinction between them.

Their highest forms are totally unlike.

of all vegetables. Now, there is no possibility of making any confusion between an animal and a rose-bush, or an apple-tree. Science ·is needed, not to inform us of the difference, but to tell us of the fundamental resemblance that all plants have to all animals.

The same is true of the lowest of the unmistakeably vegetable classes, Thallogens. This class consists of three *Affinities of Algæ, Lichens, and Fungi:* orders—Algæ, Lichens, and Fungi. These in their highest genera are distinct enough, but of some of their lower genera, as Protococcus, it is nearly impossible to say of which of the three orders they are members; and, indeed, on my view, they do not necessarily belong· to one order more than to another. They may belong to that simple original type out of which Algæ, Lichens, and Fungi have all been developed by differentiation.

of fishes and air-breathing Vertebrata. The next instance I shall mention is the connexion between the fishes and the air-breathing Vertebrata. The air-breathing Vertebrata are on the whole much higher in the scale of organization than the fishes; but the Perenni-branchiate Batrachians, which are the lowest of the air-breathing Vertebrata, approximate, not to the highest, but to the lowest of the fishes.

There are, however, some exceptions to this law, which may probably be regarded as parallel cases to that of the metamorphosis of Cirrhipedes, in which, as we have seen, *Retrograde change.* the change is retrograde—that is to say, from a higher to a lower form. One of the most remarkable instances *Acari.* of this kind that I know of is that of the Acari, or mites, which are the lowest members of a class which I believe to be descended from worms, and yet do not, at least normally,[1] present the slightest approximation to the worms. This subject must be explained in some detail.

---

[1] I say "*at least normally,*" because there are instances of Acari presenting a form which may be due to reversion to their ancestral worm-character. " Mr. Charles Robertson, Demonstrator of Anatomy in the University of Oxford, has lately described a form of Acarus found inside pigeons, chiefly among the connective tissue of the skin, the large veins near the heart, and on the surface of the pericardium. In some respects

Those classes of animals whereof the body is composed of a succession of rings from head to tail are called the Annulosa. The annulose type is a very well-marked natural type. As in other groups, the lower limit of the Annulosa is somewhat difficult to trace, in consequence of the affinities of its lower classes being less definite than those of the higher ones ; but in its higher classes, the annulose type is as well-marked a one as the vertebrate. The annulose structure is best seen in the Annelids, or true worms, in which the division into ring-like segments is distinctly visible to the eye. Above the Annelids, and, as I believe, descended from them, are the four classes of the Arthropoda, which are distinguished from the Annelids by the possession of well-developed jointed legs. The classes of Arthropods are as follow :—

Annulosa.

Their lower limit is indefinite, their higher groups have a definite character.

Annelids.

Arthropoda, descended from Annelids.

1. Myriapods (millepedes and centipedes); 2. Crustaceans ; 3. True or hexapod Insects; 4. Arachnids (spiders and mites). In these four classes, according to Professor Huxley, the head generally consists of six segments consolidated together. In the Myriapods the number of the segments of the body differs greatly as between species, and, in the lower genera of the class, probably even as between individuals of the same species; but in the Crustacea, Insects, and Arachnids, most species, according to Professor Huxley, have the whole body, including the head, consisting of twenty segments. Such characters as these cannot be adaptive; they must be hereditary, and due to community of origin. These homologies are similar to the fact mentioned in a former chapter, that nearly all the Mammalia, whether their necks are long or short, have seven neck-vertebræ. But this number is subject to variations ;[1] and if there are similar variations in the number of segments in the Arthropoda, this in no

Number of segments in head and body of Arthropods.

the Acarus described agrees with *Sarcoptes*, but has an extraordinary maggot-like appearance. The discovery of an external parasite inside an animal, in such numbers as Mr. Robertson records, is very remarkable. Colonel Montagu found such Acari in the Gannet, and Mr. Robertson has since found them in the Pelican." (Quarterly Journal of Science, January 1867.)   [1] P. 247.

degree invalidates the evidence of community of descent;
it is only another instance of the truth, that no morpho-
logical character is quite invariable.   It is to be observed
that the determination of the number of segments in an
Arthropod is generally difficult, and sometimes impossible,
in consequence of the almost perfect obliteration of the

Acari,
though the
lowest
Arthro-
pods, do
not revert
to the
worm-
type.

joints between some of the consolidated segments, analo-
gous to the consolidation together of some of the vertebræ
in all the higher vertebrate forms.   But to return to
the Acari : these are a family of Arachnids, and, though
they are the lowest of all Arthropods, they have not
reverted to the worm-like structure ; on the contrary, like
the rest of the Arachnid class, they have their segments
more completely consolidated and less distinguishable
from each other than is common among the rest of the

Pygno-
gonidæ.

Arthropod classes.   The same remarks apply to the Pyg-
nogonidæ, a crustacean family of organization so low that
they have neither a circulatory nor a distinct respiratory
system.   Their respiration is through the general surface
of the body, as it is in all the lower Invertebrates ;[1] and
yet their forms are not worm-like, but crab-like.   These
facts concerning the Acari and the Pygnogonidæ may be,
I think, most easily interpreted by supposing that they are
tribes which, instead of advancing in organization, have
fallen below the general level of the classes to which they
belong, and yet have not in any way reverted to the
ancestral worm-structure.

Classifica-
tion in a
single
series is
impos-
sible.

The first attempts that were made at zoological classifi-
cation, generally aimed at the arrangement of all species of
animals in a single series, according to their affinities, from
the lowest to the highest; or rather, as the early schools
would have expressed it, from the highest to the lowest.
" Naturalists," says Agassiz,[2] " were bent upon establishing
one continuous uniform series to embrace all animals,
between the links of which it was supposed there were no

"Natura
non facit
saltum."

unequal intervals.   The watchword of their school was
Natura non facit saltum ; they called their system *la*

---

[1] Carpenter's Comparative Physiology, p. 403.

[2] Spencer's Principles of Biology, vol. ii. p. 299.

chaine d'êtres." The doctrine that *natura non facit saltum* is now almost become an axiom, and is, I think, sufficiently proved by the fact that modern researches among extinct as well as among living organisms have not made known a single type of form fundamentally different from those which have been familiar since the dawn of the science; while they have made known a vast number of intermediate forms, and in some cases (as, notably, in that of the Cirrhipedes) they have filled up a gap by the discovery of a larval form. As it has been truly expressed, "all newly discovered forms can be arranged either *in* known groups or *between* them." [1]

But such expressions as *"la chaine d'êtres,"* or *" the organic scale,"* are inaccurate. A little familiarity with organic classification is enough to show that no single series is possible which shall represent organic affinities. The possibility of such a series is excluded by the fact that different groups generally approximate by their lower, and not by their higher members. Thus, for instance, among the Vertebrata, if we were to write the names of all the orders and genera of fishes in a series from the lowest to the highest (though not even a single class can be truly arranged in such a series), we could not go on straight to the air-breathing classes; on the contrary, it would be necessary to go back far down in the series of fishes, in order to begin that remarkable series of Perennibranchiate Batrachians which constitutes the transition from the fishes to the air-breathers. It is the same generally. When The whole groups are capable of being compared, though one may be of one group is higher than the other on the whole, it is seldom or never seldom that all the members of one group are higher than all the higher than the members of another. Thus, though animals are on the whole of whole very much higher than vegetables, the higher a kindred group. vegetables are very much more highly organized than the Protozoa, or lowest animals.

When the student has become convinced of this fact, Organic that the order of organic affinities is not a single series, his *seem* like a network.

Unless the pseudembryonic forms of the Echinodermata are an exception to this. See Note to last chapter.

first impulse will probably be to conclude that it is an inextricably complex *network*. Such a conclusion would no doubt be incomparably nearer the truth than the notion which it has superseded, of a *chain;* and I think it likely that the majority of naturalists are at present resting in that conclusion. Nevertheless, I believe it will be found, that as the notion of a single chain of affinities rested on a total misconception of the facts of comparative morphology, so that of a network, with affinities in all directions, rests on an incomplete knowledge of them. As already stated, I believe the true form of classification is that of a tree, the branches of which, after diverging, never reunite.

I believe they are in form like a tree.

The analogy of a tree may help us further. Were it possible for an intelligent man to see for the first time a large and many-branching tree without knowing anything of its mode of growth, he would at first fancy that its branches formed a network ; and it would require a good deal of careful examination before he could be quite convinced that such an inference was a purely visual illusion, and that in not a single case do they reunite after diverging. Just so, I believe the natural and plausible notion of a network of affinities is due to our imperfect knowledge. The organic tree has two main trunks, the vegetable and the animal : these, at least, do not reunite, but diverge and re-diverge into classes, orders, genera, and species, though not with the regularity that appears to be implied in those somewhat technical expressions. I do not say it is proved that groups never reunite after diverging; I only say that I believe every advance that is made in systematic biology and in true classification tends to prove it.

Groups never reunite after diverging.

It is, however, scarcely to be hoped that the outline of the organic genealogical tree will ever be traced in all its parts with even approximate fulness and accuracy. Great progress, no doubt, has been made, and more remains to make. Many connecting links of affinity have been found : some, by the more careful anatomical or microscopic study of organisms already known ; others, by the discovery of new forms, fossil as well as living ; and

Affinities will probably never be perfectly traced.

others, again, by the discovery of larval forms. And, with Many
the clearer understanding of affinities, we have come to see links have
been dis-
that some apparent affinities are not real affinities at all, covered,
and some
but merely adaptive modifications. Thus the whale tribe apparent
are not, as they appear on a superficial view to be, a group links have
been found
connecting the Mammalia with the fishes, but a group of not to be
Mammalia modified for an aquatic life, and having no re- real ones.
Whale
semblance to fishes except a merely external one. Such a tribe.
conclusion as this, though merely negative, is as important
as any positive conclusion: perhaps more so, for the pur-
pose of clearing away difficulties and anomalies in classi-
fication. But it is likely that our organic classifications
will ever remain incomplete and in some degree provi-
sional, because the materials of our knowledge are incom-
plete. Much has no doubt been lost that cannot be re-
covered. It is probable that whole classes once connected Lost links.
the lower animal forms with the Vertebrata, which have
died out during geological time, and, being without shells
or skeletons, have left no fossil remains. And, what is
quite as important in accounting for apparent gaps in the
series, it is likely that forms that once underwent a meta-
morphosis have ceased to undergo it, and have come to be
developed by a direct process. Had the Cirrhipedes lost
their metamorphoses and come to be developed directly from
the egg, we should probably never have guessed how
closely they were connected with the Crustacea ; and had
they been known only by fossil shells, their resemblance to
the Mollusca, which is only external and adaptive, would
certainly have been misunderstood, and would have caused
them to be mistaken for molluscans. But, though I do
not believe that all the gaps in our classifications will ever
be filled up, I believe it will before long be generally
recognised that affinities are divergent and re-divergent
without ever reuniting; as they ought to be on the
hypothesis that true classification is genealogical, and that
the true bond of affinity is community of descent.

It is to be observed, that on the genealogical theory of Affinity
is distinct
classification, affinity by descent does not necessarily in- from re-
volve resemblance; and the groups which are most nearly semblance.

akin by descent do not necessarily resemble each other the most. Thus the Cirrhipedes are nearly akin to the Crustacea, though in their mature state they do not resemble them ; and if they had lost their metamorphoses, their kindred to the Crustacea would never have been suspected. There may be, and probably are, many such cases in the organic kingdom of real affinity without visible resemblance ; and this possibility almost indefinitely increases the difficulty of ascertaining the true classification by descent : just as in human kindreds there is such a thing as family likeness, but the degree of likeness is no measure of the nearness of kindred ; brothers are sometimes met with who have no family likeness to each other, and cousins sometimes resemble more than brothers. But in human genealogy we have records or tradition, while we have to make out the facts of organic genealogy as we best can, from the resemblances between the various groups. There is this further parallelism between human and organic genealogy, that in men there are some kinds of characteristics, such as the form of the features, which are original and not acquired, and are consequently in some degree an index to the man's kindred ; while there are others, such as peculiarities of voice and of manner, and to a certain extent complexion, which are much more capable of alteration by the action of circumstances, and consequently are no index of kindred. Just so, in organic genealogy there are some kinds of characteristics which are subject to alteration to suit special habits of life, and, as has been already stated, are thus merely adaptive characters, and are of much less value as indications of the real affinities of the organism than those which are not so alterable.

Analogy of human kindreds.

I have shown in this chapter why, as I believe, the branches of the organic tree should diverge and re-diverge. But why should they ascend ? Why is there organic progress ? The laws of habit and variation may account for variety, for divergence and re-divergence ; but why is it that groups, after being formed, generally produce members

Why is there organic progress ?

that are superior to themselves in organization, rather than members that are inferior ?—for this is implied in the fact that groups generally approximate by their lowest members. In other words, the earliest formed species or classes of a group are generally the lowest; thus, according to the theory detailed in the last chapter, the Batrachia were the first-formed group of air-breathing Vertebrata, and have given origin by descent to the groups above them. The question now before us is, why progress is upward, and not downward; why the later-formed groups are in most cases of higher organization than their ancestors. I shall have to consider this question in the next few chapters.

I have said that the leading branches of the organic tree *An ex-* diverge and re-diverge into classes, orders, genera, and *haustive* species. To make the enumeration complete, however, I *classifica-* should have added races, families, and individuals. If *tion would* it is true that community of descent is the real bond of *species* organic affinity, a really exhaustive classification would *viduals.* include not only every species, but every individual that has ever existed; just as a really exhaustive cosmology would include not only every nebula, every star and planet, and every continent and ocean, but the position of every pebble and the fall of every rain-drop.

NOTE.

It has been urged against the validity of the argument from classification in favour of the origin of species by descent with modification, that crystalline species also are naturally classified *Crystal-* into groups, and into groups of groups, and yet there is no bond *line and* of descent between crystalline species. I think this is suffi- *species.* ciently answered by the fact that the unformed but formative material of organisms can only, so far as we know, be produced by organisms; but this is not true of crystals, as their formative material has a merely chemical source: so that the cases are not parallel.

u 2

CHAPTER XXIII.

THE CAUSES OF DEVELOPMENT.

IN the foregoing chapters I have stated a mass of cumulative evidence which, when taken together, amounts, as I believe, to a conclusive proof that species have not been independently created; but that all the species of the same fundamental type *certainly*, and all organic species whatever *probably*, have been descended from the same original stock. I regard it as certain, for instance, that all the Vertebrata are descended from one ancestor, and all the Annulosa from another; and so among plants with Endogens and Exogens. And I regard it as highly probable that those ancestors, in their turn, were descended from a still older stock, which was the original germ of all organisms whatever. I believe that in the chapter on Embryology, especially, I have pointed out the course that has been followed by the successive changes which have developed some of the lower forms into higher forms of the same fundamental type. But I have as yet scarcely *How has the transmutation of species been caused?* approached the question, by what agency the development of one species out of another by descent has been brought about. And if it is true that all organisms are descended from a few original vitalized though unorganized germs, *How has organic structure been produced?* the further question arises, how the matter of those original germs was caused to assume an organic structure; or, in other words, by what causes, acting on vitalized matter, organic structure is produced?

We must begin by trying It is a cardinal principle in scientific reasoning to begin by trying whether known causes are adequate to account for the phenomena under investigation; and it is only when

the causes already and independently known to exist are known causes. demonstrably inadequate to produce the effects, that we can with any certainty infer from the effects the existence of distinct and separate causes. From this point of view, the questions of the origin of species, and of organization, may be thus stated :—

Given the laws of the relation of life to matter and energy—or, in other words, given the chemical and dynamical properties of vitalized matter;—given also the laws of habit and variation :—are these, in combination with the action of external causes, sufficient to account for the facts of organization and morphology ? Will vitalized matter assume organization under the action of external forces, and in obedience to no other laws than chemical and dynamical ones, and the vital laws of habit and variation ?

Before we endeavour to answer these questions, let us go back on the subject, and recount what organization is. Organization, as defined in a former chapter, is the adaptation of structure to function ; or, in other words, the Organization is adaptation of every part of an organism to every other adaptation, part, and of all to the mode of life of the organism. It is tion, obvious that if any theory of the origin of organization is morphological and to be complete, it must account for histological as well as histological. morphological adaptations ; that is to say, it must not only gical. account for the adaptation of the foot for walking, of the hand for grasping, of the wing for flying, of the jaws for masticating, and of other organs each for its own special work ; it must also explain how each different kind of tissue has been formed and fitted for its function—bone for support, muscle for transforming vital into motor energy, and the other tissues of which organisms are built up, each for its own peculiar function. These two problems, it is The evident, run into each other ; nevertheless they are dis- problem twofold. tinct : and it may be thought that the problem of the origin of morphological adaptations—that is to say, the adaptation of every organ to its particular work—is a partly soluble problem ; while the origin of histological adaptations—that is to say, the adaptation of every kind of

tissue to its function—is totally insoluble. And certainly, at a first glance, the question how germinal matter has acquired the power of transforming itself into cellular tissue, bone, muscle, and nerve, appears at least as far beyond the possibility of solution as the question why oxygen and hydrogen combine into water, or nitrogen and carbon into cyanogen. Nevertheless it is worth while to inquire whether it is possible to suggest any physical causes for these transformations : if we come to the conclusion that none such are possible to assign, even such a negative conclusion will be valuable ; and if we are compelled to keep our judgment in suspense, it will be well to have stated the question. With respect to morphological adaptations—as, for instance, the question how, and by what physical process or physical cause, a limb which is homologically identical with the pectoral fin of the fish has been transformed into the leg of the quadruped, into the wing of the pterodactyle, the bird, and the bat, and into the hand of man;—with respect to this class of questions, I say, it does not appear so hopeless to seek for a solution. In speaking of the laws of habit and variation in a former chapter, it has been explained at some length how organisms have a very considerable power of adapting themselves to changing circumstances, necessitating a change in the mode of life. The problem before us may be thus stated, in words somewhat different from those employed above :—Is it possible that all of the almost infinitely complex adaptations of the organic creation can be produced by any action, *direct or indirect*, of inorganic forces on the organism, and the actions of the organism in response thereto ; the effects of all such actions being, of course, accumulated by hereditary habit, and complicated with the laws of the correlation of variations ?

The problem stated.

When I speak of a direct process, I mean, of course, the process of spontaneous self-adaptation to circumstances, of which all organisms are in some degree capable. By an indirect process, I mean that of " natural selection among spontaneous variations," according to Darwin's law. These two causes—self-adaptation and natural selection—are the

Two possible processes : self-adaptation, and natural selection.

only *purely physical* causes that have been assigned or that
appear assignable, for the origin of organic structure and
form.   But I believe they will account for only part of the I believe
facts. It is my belief that all such solutions of the problem in an Orga-
nizing In-
are inadequate, and that no solution of the questions of the telligence,
origin of organization and the origin of organic species can over and
above
be adequate, which does not recognise an Organizing Intel- these,
ligence over and above the common laws of matter. Or, in
other words, I do not believe that the relation of means to distinct
purpose in organization is a mere case of the law of cause from
physical
and effect.   This is what I aim at showing in the present causation.
and the following chapters. But we must begin our inquiry
by considering *how much* of the facts of organic structure
and vital function may be accounted for by the two laws
of self-adaptation and natural selection, before we assert
that any of those facts can only be accounted for by
supposing an Organizing Intelligence.

Here I must guard myself beforehand against a miscon-
ception.   I shall be compelled to say that some organs
and structures may have been formed by the forces of
ordinary matter acting on and through the laws of Habit,
while other organs and structures can only be the work of
Intelligence.   But this is not an accurate way of speaking.
It is only a concession to that narrowness of our under-
standing which compels us to think and speak of things
apart which in nature are always and necessarily united.
Life does not suspend the action of the ordinary forces of
matter, but works through them.   I believe that wherever Where life
there is life there is intelligence, and that intelligence is is, there is
intelli-
at work in every vital process whatever, but most dis- gence:
cernibly in the highest.   In every vital action, whether and most
discernible
formative, motor, or sensory, whether conscious or un- in the
highest
conscious, the ordinary forces of matter are at work, functions.
directed and controlled by life and intelligence.   But,
though I believe that these two sets of causes act in every
manifestation of life,—the forces of inorganic matter on
the one hand, and life with intelligence on the other,—
it is a mere statement of obvious fact to say that the
inorganic causes are most discernible in the lower vital

functions, as in nutrition, circulation, and respiration ; and life and intelligence are most discernible in the formation and in the action of the organs of sense and of thought. Nutrition, circulation, and respiration are in a great degree to be explained as results of physical and chemical laws ; and I believe that, as I shall endeavour to show, the origin of the organs in which those functions are carried on may be in some degree explained by the operation of those same laws. But sensation, perception, and thought cannot be so explained. They belong exclusively to life ; and, similarly, the organs of those functions—the nerves, the brain, the eye, and the ear—can have originated, I believe, only by the action of an Organizing Intelligence.

The laws of habit are not intelligent.   I believe intelligence to be a concomitant of all life, but I do not think that all the laws of life are to be referred to vital intelligence. The laws of Habit are purely vital laws, but I do not see any element of intelligence in them.

I have now to explain in what way I think that some of the simpler of the formative processes of organization may be accounted for by the action of inorganic forces on vitalized matter. What follows on the origin of cellular tissue, of circulatory vessels, and of respiratory organs, is all suggested by the second volume of Herbert Spencer's "Principles of Biology," and is mostly taken from it.

We have seen that in most cases, though not in all, the first product of organization is the cell. Many of the lowest Algæ consist of but a single cell, and the embryo of the higher plants and animals before they begin to assume any distinctive form consist of cellular tissue. A very probable cause of the first formation of cells is that various influences from without acting on a minute mass of vitalized but unorganized matter, determine a slight hardening of the surface. The exact nature of the action is probably undiscoverable ; but all I wish to insist on is, that it must be due to some agency that acts differently on the inside and on the outside of the mass of germinal matter. By

Formation of cellular tissue.

repetition of this process, a habit is produced of forming cells; and this becomes hereditary, so that cells continue to be produced in the midst of the germinating seed or of the growing embryo, and other situations where the chemical actions are alike in the inside and on the outside of the cell, and where consequently cells could not continue to be formed in the same way that I suppose them to have been formed at first.

This is a mere speculation, and, so far as I am aware, has no evidence except what it derives from internal probability. But there is more direct evidence as to the origin of circulatory vessels. We know that streams have Circu- excavated their own channels, and there appears to be a latory very strong probability that the circulatory channels in vessels, organisms have been formed by the flow of the nutritive formed. fluids. It is stated on the high authority of Von Bär, that in the animal embryo blood appears before blood-vessels are formed, and circulation begins before there is a heart to propel it;[1] and we know that the embryonic states of the higher forms generally represent the permanent states of the lower ones. We may consequently infer that the earliest circulation was not due to the action of a heart, or to muscular action at all. The circulation in air-breathing Cause of plants is principally due to evaporation from the leaves, circulation but this will not apply to aquatic or embryonic organisms. breathing A physical cause for their circulation, however, may be plants; assigned. It has been ascertained[2] that if two liquids have access to the same capillary tube, and one of these has a stronger affinity than the other for the substance of the tube, the one that has the strongest affinity will drive the other before it. Arterial blood has a stronger affinity

---

[1] Carpenter's Comparative Physiology, p. 717.

[2] Carpenter's Human Physiology, p. 255. The discovery of this law, and its application to the facts of circulation, are ascribed to Professor Draper. Of course it is true of porous substances, as well as of capillary tubes.

This law will account for the capillary circulation in the respiratory organs, as well as throughout the tissues. Throughout the tissues, the arterial or oxygenated blood is attracted by the carbon of the body. In the respiratory organs, the venous or carbonated blood is attracted by the oxygen of the lungs.

and in the lowest animals. than venous blood for the substance of the tissues; and Dr. Carpenter regards this action as being probably at least one cause of the capillary circulation. Some such action as this must probably be the cause of the motion of the nutritive fluid, not amounting to circulation, which has been observed in the Sertularian Hydrozoa. These animals have nothing of the nature of a heart, and yet the nutritive fluid, which corresponds to the blood of the higher animals, flows towards growing parts, and away from dying ones.[1]

Suppose now that a movement of the nutritive fluid— of sap or blood—by permeation through the cellular tissue, has been commenced, whether by this means, or, as in plants, by evaporation from the surfaces exposed to air and sunbeams;—and if proof is needed that the circulation of air-breathing plants is so caused, it is proved by the fact that there is hardly any circulation in the water-breathing kinds;—suppose, I say, that the circulation has begun from either of these two causes, or from any other; the currents will tend to excavate channels for themselves through the cellular tissue, exactly as rivers tend to excavate their own channels; and the formation of such channels will become hereditary. This is no mere hypothesis; it has been as directly verified as the nature of the case admits of. A perfect gradation may be seen in air-breathing plants, from cellular tissue to perfectly-formed vessels. First, ordinary cellular tissue; next, cells elongated in the direction in which the sap flows, as determined by the place of greatest evaporation; next, cells having their separating walls broken or dissolved away, so as to unite them into tubes; finally, tubular vessels showing no longer any vestige of cell-structure. I do not mean that this whole course of development takes place in the lifetime of any one plant; but the comparison of these transitional stages makes it highly probable that such has been the course of development through successive generations; and there are many cases where a part of the transition may be witnessed in the individual.[2]

Tendency of circulation to form channels for itself.

[1] Carpenter's Comparative Physiology, p. 633.
  For details see Spencer's Principles of Biology, Part V. chap. iv

I now come to the organs of respiration; and I have to Respira-
begin this subject with the remark, that among the lower organs:
tribes of animals generally, those organs are surprisingly their
inconstant, not only as to their position, but as to their
existence.   This, I think, is more remarkably the case
among the water-breathing Gasteropodous Mollusca than
in any other class, but it is generally true of the aquatic
Invertebrata; and in close connexion with this is the fact,
that the most remarkable cases in the animal kingdom
of organs that assume new functions totally unlike their
original ones are among respiratory organs. This extra-
ordinary plasticity of the respiratory organs is evidently
connected with, and I believe is a result of, the fact that
among the lowest animals, and in some degree among the
highest, the function of respiration belongs to the whole
surface.   " The alimentary canal respires, digests, and
excretes in the larva of the dragon-fly and in the fish
Cobites," [1] neither of which is a very low organism. Among
the Batrachia a great proportion of the respiration takes
place through the skin; [2] in the axolotl, which is one of
that class, the importance of the branchiæ is so slight that
their removal does not appear to injure the animal, or even
to increase the necessity for coming to the surface of the
water in order to breathe air; [3] and even in man there is a
slight amount of respiration through the skin. [4]   I believe
it may be safely asserted that all land animals have distinct
respiratory organs. [5]

Respiration, though it takes place in living beings, is Respira-
essentially a merely chemical and physical process; it tion is a
physical
consists in absorbing oxygen, and giving out the carbonic process.

[1] Darwin's Origin of Species, p. 220.
[2] Carpenter's Human Physiology, p. 293.
[3] Memoir by Auguste Dumeril, translated in the Annals of Natural
History, December 1867.
[4] Carpenter's Human Physiology, p. 293.
[5] Those of the earthworm have remained unknown till lately.   But it is
now stated that its "respiratory apparatus is an aqueous sac, lined with
vibratile cilia, within the abdominal cavity, on either side of the body."
(Dr. Cooté on Nerve Structure and Force, Quarterly Journal of Science,
April 1867.)   The respiratory organs of the land mollusca are well known.

acid which is formed by slow combustion throughout the
body. The means by which the organism effects this
change is to bring the blood into virtual contact with the
air or water, according as the animal is an air- or a water-
breather, over an extensive surface of very thin membrane,
through which the exchange takes place spontaneously by
that physical process known as the " diffusion of gases." [1]

If now in one of those animals, such as many of the
naked marine Mollusca, in which the function of respira-
tion is discharged by the whole surface of the body, and
Possible there is no distinct respiratory organ ;—if in one of these,
origin of
respiratory I say, a part of the skin, from any spontaneous variation,
organs. becomes thinner than the rest, or more abundantly sup-
plied with blood-vessels ; or if the blood under one part
of the skin contains a somewhat larger proportion of car-
bonic acid, from the waste of the body, than in other
places; any one of these causes will produce a more rapid
exchange through that part of the skin than through any
other, between the carbonic acid of the blood and the
oxygen of the external medium, and that part will be a
rudimentary, or nascent, respiratory organ; the flow of
blood to and through that part will be increased by the
chemical unlikeness between venous and arterial blood, in
virtue of the law already stated ; and it appears tolerably
well established, that an increase in the flow of blood
through any part will cause it to grow and develop.

In order to form a complete theory of this subject, it
would be necessary to explain, further, why the nascent
respiratory organ not only develops, but develops into that
structure which is specially needed for the purpose of
respiration. This, however, I am not able to do, and I
doubt whether it is possible. Unlike the origin of cellular
tissue, or the formation of sap-vessels by the union of cells,
the present problem is an extremely complex one.

Whatever may be thought of this speculation (and I
only advance it as such), it is consistent with what we
know of the development of the branchiæ of the Mollusca,

---

[1] Carpenter's Human Physiology, p. 264.

which arise by budding from the skin of the embryo.[1]
For if embryology is an index of descent (and this, I think,
cannot be reasonably doubted), we must suppose that the
development of the individual repeats, in a short time, the
development which occupied untold generations of the
species. It can scarcely be necessary to repeat, that all
actions whatever, tending to modify the nature of an
organism, will accumulate their effects through successive
generations.

I will now go on to mention two remarkable instances,
in which organs originally employed for another purpose
have become converted into respiratory organs.   These
two instances include the principal, though not the only
classes of air-breathing animals.

The leech and the earthworm have two small sacs in Homo-
each segment opening on the external surface of the body. logies of
The function of these appears to be to secrete mucus. ratory
But there is a gradation, through the Millepedes and organs of
insects :
Centipedes, between these sacs and the air-tubes or tra-
cheæ by which insects respire.[2]   The tracheæ of the insect
are consequently homologous with the mucus-sacs of the
worm ; and, if the development theory is true, the sacs,
being no longer needed for the purpose of secreting mucus,
have, through successive generations, changed the character
of their lining, and have extended through the body, so as
to become transformed into respiratory organs, adequate to
meet the wants of such active animals as insects.   What
made the transformation possible, was the fact that every
surface exposed to the air or the water in which the animal
lives is (if not too much indurated, like the shell of a tor-
toise or of a crab) in some degree a respiratory surface.[3]

The wings of insects are due to a transformation which
is even more wonderful than this.   Unlike the wings of
Pterodactyles, birds, and bats, they are in no way homo-
logous with legs ; on the contrary, they are now generally
believed to be appendages of the respiratory system ; the

[1] Spencer's Principles of Biology, vol. ii. p. 293.
[2] Carpenter's Comparative Physiology, p. 748.
[3] Carpenter's Human Physiology, p. 293.

only organs with which they are homologous are the leaf-
like expansions that arise from the openings of the tracheæ
of some aquatic larvæ; though it is very difficult to guess
by what kind of a process leaf-like branchiæ came to be
used as wings. The difficulty is not so much to under-
stand how the wing-form was produced (for branchiæ may
be produced in one form almost as easily as in any other),
as to understand how the habit of flight could originate;
for, as a rule, there are no sudden transitions in nature.
But it is to be remembered that motor habits are more
variable than formative ones.

of air-
breathing
Vertebrata. The next transformation that I have to mention is not
only one of the most important, but one of the best under-
stood, in the whole organic creation. I mean the transi-
tion from the swim-bladder of fishes to the lungs of the
air-breathing Vertebrata. I have spoken of this several
times already; but I have now to notice the significant
Origin of
the latter. fact that all the Batrachia, through which class the transi-
tion takes place, are inhabitants of fresh water.[1] Fresh
water is liable to be dried up; and I believe the Batra-
chians to be descended from fishes, which, when water was
failing them, acquired the power of breathing air by means
of the swim-bladder.[2] This would be almost incredible,
were it not for the general fact of the inconstancy of the
form and position of the respiratory organs, and the special
fact of the preservation of the Perennibranchiate order,
which presents a series of connecting forms. And what
still further strengthens the case, is the remarkable set of
The
axolotl. facts lately discovered concerning the axolotl. This animal
is a Batrachian, and has till now been regarded as a Peren-

[1] Except the land-newt, or land salamander, and perhaps one or two
other species, which are not aquatic at all.
[2] See Spencer's Principles of Biology, vol. i. p. 395, and vol. ii. p. 325.
I must say, however, that I think his attempt to account for the origin
of the swim-bladder is quite unsuccessful. He thinks it arose from fishes
acquiring the habit of swallowing bubbles of air, at a time when the supply
of oxygen in the water was failing in consequence of the increasing heat
of the weather. This appears to be possible only in shallow fresh waters,
and I do not think there is the slightest reason for believing cod and other
sea-fish that have swim-bladders to be descended from fresh-water species.

nibranchiate. But the axolotl as hitherto known, though
it is a mature form by the usual test of being able to pro-
pagate,[1] proves to be a larva in the sense of having yet
to undergo metamorphosis. The specimens observed in
captivity in France, from which alone our knowledge of
their metamorphosis is derived, sometimes undergo meta-
morphosis and sometimes not, without any assignable reason.
Like other Batrachians, they lose their branchiæ when
they undergo metamorphosis, in addition to other changes;
and if the branchiæ are removed (under which operation
the animal does not appear to suffer in health), the chance
of the metamorphosis taking place is increased, though it
is still very uncertain.[2]

These facts are most interesting, partly as showing that
an animal which has not undergone its final metamor-
phosis may yet propagate; and partly as showing how
variable is the fact of fianl metamorphosis, as between in-
dividuals of the same species. This last is an instance of
the general law, that those characters which are variable as
between allied species are also variable as between indi-
viduals of the same species : for no one doubts the real and
near affinity between the Perennibranchiates, which never
lose their branchiæ and are in fact permanent tadpoles, and
the Caducibranchiates, such as the newt and the frog,
which lose their branchiæ when they cease to be tadpoles.[3]
The irregularity of the metamorphoses of the axolotl sug-
gests also, that the first individual of a Perennibranchiate
species that lost its branchiæ, and gave origin to a race
of Caducibranchiates, may have done so accidentally, in
consequence probably of the branchiæ drying up and
withering for want of water.

[1] *I.e.*, sexually. No vertebrate ever propagates in any other way.

[2] Memoir by Auguste Dumeril, translated in the Annals of Natural
History, December 1867.

[3] I do not mean to imply that it would be a natural classification to
divide the Batrachia into Perennibranchiates and Caducibranchiates.
The right division of the class is into (1) the newt or salamander tribe,
having four limbs and a tail; this includes the Perennibranchiates :
(2) the frog tribe, having four limbs but no tail : (3) the Cæcilia genus,
which are like serpents in form, having no limbs.

A fact may be mentioned of the vegetable kingdom, which is strictly analogous with the power of various parts of the external surface of animals to assume the respiratory function. Leaves are the organs with which plants decompose the carbonic acid of the atmosphere; *Stems taking the functions of leaves.* but there are some tribes of plants, of which the Cacti are the best known, that have no true leaves ; and in them the stems are green like leaves, and discharge the function of leaves. *Inter-change of function between secretory organs.* And it belongs to the same order of facts, that one secreting organ frequently shows itself able, though imperfectly, to discharge the function of another. This has been observed in cases of disease in man, and in animals when one of the organs has been removed or otherwise experimentally interfered with.[1]

I have now brought forward a number of facts and arguments, which all tend to show that *up to a certain point* tissues and organs are capable of being formed by the *Will purely physical actions account for the origin of all structures?* action of purely physical forces on vitalized matter. But it is important to observe, that all the instances I have mentioned are taken either from the vegetable kingdom, or from the vegetative, or nutritive, systems of animals ; and no way appears conceivable by which the actions of external forces on the organism can account in any similar way for the origin of the peculiarly animal tissues—for the formation of muscle and nerve. If their origin is explicable at all, it must, I think, be due, not directly to the action of inorganic forces on the organism, but to the actions of the organism itself in response to impressions from without. But a satisfactory physical theory of the origin of muscle and nerve is out of the question in the present state of science, nor do I feel sanguine of ever attaining to it. I only do not say it is impossible.[2]

[1] Carpenter's Human Physiology, p. 374.
[2] I say this after reading the speculations on this subject in the second volume of Spencer's Principles of Biology. He admits that his theory of the origin of nerve-fibres does not account for ganglia. Now nerve-fibres and ganglia are always found together, in all classes of animals, and they are developed together; so that no theory is good for anything that

One of the most important laws to be borne in mind in Organs improve with use: the diffi- culty is first origin. all speculations of this class, is that law in virtue of which every organ improves with use. This indeed is a parti- cular case of the law of self-adaptation. Exercise, pro- vided that it is not beyond the limit of what is good for health, increases the strength of a muscle or the sensitive- ness of a nerve. The difficulty is not to account for almost indefinite improvement in an organ, but to account for its origin. I cannot make any suggestion whatever as to the possible origin of nerve, but perhaps it is not absurd Origin or nerve and muscle: to think that the fibrous structure of muscle was originated by the sarcode substance of the earliest structureless though living beings acquiring the habit of contracting in one direction more readily than in any other. We know that the sarcode has contractile power in organisms which have no visible structure, and the simplest rudimentary muscular structure consists in a fibrillation of the sarcode.[1]

I have now stated my belief that some of the simpler structures belonging to the vegetative system have pro- bably been produced by the action of inorganic forces on the organism; and that muscular structure may possibly, though I do not say probably, have been produced by the action of the organism itself in response to impressions from without. Of course these two factors are always both present, though acting in very unequal proportions in different cases. But there are structures for the origin of which it is, I believe, utterly impossible to account by any such merely physical theory; and which can only be referred to an organizing intelligence. I refer to such organs as of the eye and the ear. the eye and the ear. If it is certain, as I think it is, that the flow of the nutritive fluids through cellular tissue, for successive generations, must have a tendency to form a rudimentary circulating apparatus, it is at least equally obvious that the action of light falling on the eye for any number of generations can have no similar tendency to produce the optical apparatus of the eye. Nor can the

attempts to account for the one without the other. It would be different if the ganglia were an *outgrowth* of the fibres, as the brain is of the spinal cord.

[1] Dr. Wyville Thomson on the Embryology of the Echinodermata, Natural History Review, October 1864.

constant exercise of the eye in the act of seeing have any
such effect. The exercise of the eye, within the limits
of what is healthful, does no doubt tend to increase the
sensitiveness of the retina; and I do not say it is im-
possible, though I do not admit it as probable, that the
muscular arrangements to which the mobility of the eye-
balls and eyelids is due may have been produced by the
effort to move them, continued through successive genera-
tions; and that the expansion of nerves over the retina
may have been produced by the constant stimulation of
the nerves themselves. But no such merely physical theory
will account for the origin of the special complexities of
the visual apparatus. Neither the action of light on the
eye, nor the actions of the eye itself, can have the slightest
tendency to produce the wondrously complex histological
structure of the retina; nor to form the transparent
humours of the eye into lenses; nor to produce the deposit
of black pigment that absorbs the stray rays which would
otherwise hinder clear vision; nor to produce the iris, and
endow it with its power of partly closing under a strong
light so as to protect the retina, and expanding again when
the light is withdrawn; nor to give the iris its two nervous
connexions, of which one has its root in the sympathetic
ganglia, and causes expansion, while the other has its root
in the brain, and causes contraction.[1]

*No physi-
cal causes
will
account
for the
origin of
the eye
and the
ear;*

I have spoken first of the organs of special sense, because
it is in their case that the impossibility of formation by
any physical action is most obviously evident. But there
are other cases where the impossibility is equally demon-
strable. When any structure is formed or modified either
by the action of external forces, or by the action of the
organism itself, this is a case of self-adaptation—not of
adaptation only, but of self-adaptation. But, as we have
seen, the complexities of the eye and of the ear cannot
be so produced; and, quite independently of any special
complexity, there are many structures in which the rela-
tion of structure to function is such as to make any phy-
sical explanation of their formation as totally impossible
as in the case of the eye and the ear, though for an entirely

---

[1] Carpenter's Human Physiology, p. 639.

different reason. Take the case of protective structures;
the skin hardens and thickens in any place that is exposed
to rough usage; this is a case of self-adaptation, and it
may become hereditary, as in the instance of the knuckles
of the gorilla.[1] But such cannot be the origin of the shell *nor of the*
that protects the bird's egg. Without this protection, no *egg-shell,*
egg could be hatched, and the whole tribe of birds would
perish. But the contact of comparatively hard and rough
substances, which makes the shell necessary, cannot have
had the slightest tendency to produce the shell; for the
shell is formed, and from the necessity of the case must be
formed and completed, before any such contact can take
place.[2] And the law of hereditary habit, universally true
as it is, makes no difference here; for it appears utterly
impossible that egg-shells can ever have been formed
under different circumstances from the present. The same *nor of the*
is true of the bony or cartilaginous skulls that protect *skull,*
the cephalic ganglia in the Cephalopoda (cuttlefish and
nautilus), and in the Vertebrata, and of the hard woody *nor of*
shells that protect the seed in nuts. The fact that there *nutshells.*
is something to protect, is not a *physical* cause of the
production of a protective structure.

In this chapter I have considered how far the facts of *Summary.*
organization can be accounted for by the direct action of
inorganic forces on the organism, and by the actions of the
organism itself; and I have come to the conclusion, that
such a purely physical account of the origin of organization
is probably valid in the case of some of the simpler
structures belonging to the vegetative system; very doubt-
ful in the case of the peculiarly animal ones, as muscle
and nerve; and demonstrably, not merely inadequate, but
totally inapplicable to the case of the complexities of the
organs of special sense, and to many cases, not necessarily
complex ones, in which the structure is produced under
such circumstances that the peculiar work for which it is
adapted can have no tendency to originate it. In the
next chapter I shall have to consider how much may be
explained by the law of Natural Selection.

[1] Spencer's Principles of Biology, vol. ii. p. 295.   [2] Ibid. vol. i. p. 440.

CHAPTER XXIV.

NATURAL SELECTION.

IN the chapter on Distribution, while stating my belief that the remarkable similarity, without identity, between the living species inhabiting the same region during successive geological periods is due to the bond of descent, I said also that the species inhabiting any region at present are not the direct lineal descendants of those which dwelt there in the last geological age ; but that the

Natural selection defined

descent has been modified in accordance with a peculiar law. The law I mean is that of " natural selection, or the preservation of favoured races in the struggle for life." (I quote these words from the title-page of Darwin's work on " The Origin of Species.") But as Darwin's work, in which the law of natural selection was first stated and proved, is a well-known and very readable book, it is needless for me to go into much detail. I speak of it as a law that is proved. There is the greatest possible difference of opinion as to how much the law will account for; but no one who has the slightest knowledge of the subject can doubt that it is a truly operative law.

to be among sponta- neous variations.

Before there can be selection, there must be something among which to select ; and the full designation of the theory is " natural selection *among spontaneous variations.*" In the chapters on Habit and Variation, we have seen that species are not absolutely constant in their characters, but are liable to slight, and sometimes considerable variations, which may become very great if they are added up and accumulated through successive generations. We have seen also that variation is stimulated by change of the

circumstances of life and by mixture of races, when these
do not go further than what is good for the health and
vigour of the species; and that some species are more
variable than others. It has also been shown that when
any particular character in a race once begins to vary, it is
apt to acquire a habit of varying; and it is obvious how
this fact must facilitate the accumulation of variations
through descent in particular directions. I mean that
when any one character becomes variable, such as the
form of the beak in the domestic pigeon, it will be com-
paratively easy to obtain by selection new breeds that
differ from the parent ones in that point.

Domestication is a great change in the circumstances of
the life of both animals and vegetables, and cross-breeding,
so as to produce slight mixtures of race, is systematically
practised with many of the domestic races of animals;
and these two causes are amply sufficient to account for
the great variability which is common, though perhaps Causes of
not universal, among domesticated races, vegetable as well variation
as animal. It is, I think, an unsettled question, whether tic races.
a perceptible degree of variation ever takes place, at least
among the higher animals and vegetables, without the
stimulus either of change of circumstances or of mixture of
race; and it will not be easy to decide the question, for
evidence is difficult to obtain concerning wild races, and
the variability of the domestic ones is probably due to the
change in the conditions of their life effected by their first
domestication, and to subsequent crossings of the breed.

But it is certain that changes in the circumstances of Changes
life must, throughout geological time, be constantly occur- of circum-
ring, and stimulating variation. Geological, and I may geological
add astronomical,[1] revolutions alter the climate and time.
physical geography of whole continents; and quite inde-
pendently of this, geological revolutions effect vast changes
in the circumstances of the life of species, by either forming

---

[1] See Mr. Croll's Papers on the Glacial Climate, and kindred subjects,
in the Philosophical Magazine. I do not agree with all his results, but
I think he has done great service to science by showing that the changes
in the earth's orbit must produce climatic changes.

or removing barriers to migration. Besides—as Darwin was, I believe, the first to state, with any emphasis proportioned to the importance of the fact—any change in the distribution of one species is almost certain to produce changes in the conditions of the life of other species, by altering the character and abundance of their food, the character and number of their enemies, and the character of the species with which they have to compete for a subsistence. The importance of this element of competition, or "struggle for existence" (to quote again from Darwin's title-page), was also first insisted on by Darwin. I shall have to return to this subject shortly. It is very difficult to say how much effect is to be ascribed to mixture of races occurring in a state of nature. Among plants the pollen of one is carried to the stigma of another, by the wind or by insects, quite at random; and in this way races may be mixed. But, for reasons to be explained further on, it is not common for two varieties of the same species to be found in the same habitat, and this must tend to prevent mixture. The same is true among animals; and besides, among the higher animals, which have a mental nature and a power of choice, it seems certain that this will be exercised in a way that will keep races separate.[1] For these reasons, I am inclined to think that there is very little mixture of races in a state of nature, and that the stimulus to variation is chiefly given by changes in the circumstances of life.

Struggle for existence.

Races probably mix little in nature.

Having spoken of these preliminary questions, it is time to state the manner in which natural selection will take place.

All organisms multiply so rapidly that when any geological or climatic change opens a new habitat to a species, a time which is geologically very short will suffice to stock the new habitat with as large a population of that species as it can support; and when this has been done, many more

Rapid increase.

---

[1] This is true of domestic races. When any degree of freedom is permitted, different breeds of the same species, as sheep or pigeons, prefer to herd and to breed each apart. (Darwin on Variation under Domestication, vol. ii. chapter xvi.)

individuals are born every year than can possibly come to maturity. Consequently there will be a "struggle for existence." If any spontaneous variation takes place which gives an advantage in that struggle to its possessor, the individual so favoured will have the best chance of surviving and leaving offspring, and the favourable variation will probably be inherited. Thus, by preserving the best and weeding out the inferior ones, the race will be gradually improved. This process is exactly the same in principle as that by which the breeds of domestic plants and animals have been improved; the best are preserved, and the others are destroyed or not permitted to breed.

Favourable variations will be preserved and inherited.

This short explanation will make it obvious how selection, whether by natural or by human agency, can improve and perfect a breed. But it must be further explained how selection can produce, from the same parent stock, two or more races differing not only from the parent stock, but from each other. For this purpose, however, it is only necessary that selection should act on two different and divergent lines of descent, and that the individuals selected in the different lines should be selected for different qualities. The various breeds of the dog, for instance, have chiefly arisen by selection under domestication; and they are distinct, because selection has been applied for different purposes in the different breeds : in some for fidelity and sagacity; in others, for power of hunting by scent; in others, again, for fleetness. I believe this account of the origin of the breeds of dogs is historically true; it is certainly possible; and there cannot be the slightest doubt that such has been the origin of the domestic breeds of the pigeon,[1] which vary from each other more than those of any other domestic animal. Selection, constantly applied for different qualities, must necessarily give origin to distinct breeds, because the different qualities can be but seldom found together in any unusual degree. Thus, among dogs, if the qualities of keenness of scent and fleetness are not correlated, which they certainly are not; and

Divergence of character, how produced by selection in domestic races,

[1] Darwin's Origin of Species, p. 24.

if one dog in every hundred excels in one of those qualities, and the same proportion in the other, to a sufficient degree to attract the attention of the selector; the chance of any dog excelling in both will be only the second power of one in a hundred, or one in ten thousand, which chance is so small that it may be left out of account.

and in wild races. It is obvious that selection by natural agency may act in exactly the same way as selection by human agency. Wild beasts of prey that excel either in fleetness or in scent will have the best chance of surviving and leaving off-spring; and these favourable variations will be added up and accumulated through an indefinite number of genera-tions. As I have just shown, it is not at all likely that two favourable variations will occur in the same individual; and an unusual degree of fleetness in one of a race that hunts by scent, or an unusual power of scent in one of a swiftly running race that hunts by sight, would probably be comparatively useless, and consequently would not tend to the preservation of that individual. What will be most valuable, and consequently most conducive to the preser-vation of the individual, is probably a slightly increased degree of some favourable peculiarity that the race already has in a tolerably high degree; especially as, by the laws of self-adaptation and hereditary habit, the race will have begun to be adapted in its whole structure to the mode of life to which its favourable peculiarity is suited. Thus we may expect sagacity and wariness to become characteristic of those animals which hunt by scent, especially if they are gregarious. Besides, a race produced by the selection of individuals for any one character will necessarily have that character, on the whole, more variable than the rest of the organism; and, as we have seen in speaking of the laws of variation, a character, or an organ, that begins to vary is apt to continue variable; so that favourable varia-tions will be more likely to occur in the character that constitutes the principal differentia of a breed, than in any other of its characters. It is, as already stated, an observed fact that this is so. For these reasons, different breeds will continue distinct and divergent.

Here occurs a difficulty which Darwin appears not to
see, but which H. Spencer thinks fatal to the theory as
applied to the highest animals. Among animals that
unite for each birth and wander much, will not variations,
no matter how favourable, be lost and merged in the second
generation, by the union of the individual possessing the
favourable variation with others that are without it ?[1] It
is quite obvious that the domestic breeds of animals could
not be kept distinct, if free inter-breeding between different
varieties were permitted.[2] I am inclined, however, to think
that this objection is sufficiently answered by the fact, that
most varieties in a state of nature are local varieties : so
that while natural selection is forming a variety, suited to
the locality, by preserving the individuals suited to it and
destroying the rest, this action will not be much interfered
with by the race getting crossed with other varieties.
Dissimilar habits of life will also probably have con-
siderable effect in keeping the individuals of different
races apart : and, as we have seen, races are kept apart by
their instincts among the higher animals, and probably
among all animals.

How will incipient races be kept apart?

By being local.

How wild races are kept distinct.

I believe that natural selection will account for much
which self-adaptation will not account for.[3] To take one
very curious instance : so far as I can see, natural selec-
tion is capable of giving origin to the bat's wing. Once
the wing is formed, self-adaptation will no doubt give the
necessary power to the wing-muscles ; but self-adaptation
cannot, I think, have any tendency to produce that ex-

Origin of the bat's wing.

[1] Spencer's Principles of Biology, vol. i. p. 454.

[2] "The prevention of free crossing, and the intentional matching of indi-
vidual animals, are the corner-stones of the breeder's art. No man in his
senses would expect to improve or modify a breed in any particular
manner, or keep an old breed true and distinct, unless he separated his
animals." (Darwin's Variation under Domestication, vol. ii. p. 85.)
"Cats, which from their nocturnal habits cannot be selected for breeding,
do not yield distinct races in the same country." (Ibid. vol. ii. p. 236.)

[3] I may here mention Darwin's belief, that what is called the acclima-
tization of a race of plants is really, in some cases, the production of a
new and hardier race by selection. It is obvious that natural selection may
operate among plants grown in a garden but not under glass, by killing the
least hardy and preserving the most so. (Origin of Species, p. 169.)

tension of the fingers, and of the skin over the fingers, which constitutes the wing.

The bat's wing, when in the nascent state, probably resembled the parachute of the flying squirrels. I quote the following from Darwin:[1] "Look at the family of squirrels : here we have the finest gradation from animals with their tails only slightly flattened, and from others, as Sir J. Richardson has remarked, with the posterior part of their bodies rather wide and the skin on their flanks rather full, to the so-called flying squirrels; and flying squirrels have their limbs and even the base of the tail united by a broad expanse of skin, which serves as a parachute, and allows them to glide through the air to an astonishing distance from tree to tree. . . . Let the climate and vegetation change, let other competing rodents or new beasts of prey immigrate, or old ones become modified, and all analogy would lead us to believe that some at least of the squirrels would decrease in numbers or become exterminated, unless they also became modified and improved in structure in a corresponding manner. Therefore I can see no difficulty, more especially under changing conditions of life, in the continued preservation of individuals having fuller and fuller flank-membranes, each modification being useful, and each being propagated, until, by the accumulated effects of this process of natural selection, a perfect so-called flying squirrel was formed. Now, look at the Galeopithecus, or flying lemur, which formerly was falsely reckoned among bats. It has an extremely wide flank-membrane, stretching from the corners of the jaw to the tail, and including the limbs and the elongated fingers : the flank-membrane is also furnished with an extensor muscle. Although no graduated links of structure fitted for gliding through the air now connect the Galeopithecus with the other Lemuridæ, yet I see no difficulty in supposing that such links formerly existed, and that each had been formed by the same steps as in the case of the less perfectly gliding squirrels ; and that each grade of structure was useful to its possessor. Nor can I

Extract from Darwin.

Flying squirrels.

Flying lemur.

[1] Origin of Species, p. 208.

see any insuperable difficulty in further believing it possible that the membrane-connected fingers and fore-arm of the Galeopithecus might be greatly lengthened by natural selection : and this, as far as the organs of flight are concerned, would convert it into a bat. In bats which have the wing-membrane extended from the top of the shoulder to the tail, including the hind-legs, we perhaps see traces of an apparatus originally constructed for gliding through the air rather than for flight."

It may be necessary to state distinctly, that no one supposes the bats or the flying lemur to be descended from a squirrel. The unlikeness of the other parts of the organism excludes this. But Darwin believes, and I agree with him, that their wings have been produced by the improvement of an organ which originally resembled the parachute of the flying squirrels. *Bat and flying lemur not descended from a squirrel.*

I mention this instance as the best I can find, of organs that may have been produced by natural selection, and cannot have been produced by any process of self-adaptation. The membranes of the flying squirrel, the flying lemur, and the bat, are simple organs ; and those of the flying squirrel, at least, are not closely connected with the other parts of the organism : that is to say, their presence does not cause any very great deviation from the usual structure of squirrels. These two facts, that the membranes in question do not consist of a number of correlated parts, but are simple organs, and that they have no close correlation with the other parts, make this a peculiarly good case to isolate in thought, so as to make it the subject of reasoning. It is certain that the flying squirrels can take much longer leaps than they could if they had no membranes, and it needs no proof that this power must be useful to them. But it is, I think, equally obvious, that the habit of leaping cannot have any tendency to develop such membranes, or to increase their size after they begin to be developed. Self-adaptation thus fails to account for this very simple change. Natural selection, however, here comes into play. I agree with Darwin in thinking that the preservation, for generation *Membranes not produced by self-adaptation, but by natural selection.*

after generation, of squirrels that had the fullest skin on their flanks, and were thus best able to escape their enemies by taking long leaps, is quite an adequate cause for the origin of such a structure as the membrane of the flying squirrel. Further development into such a perfect flying

Origin of the bat's wing.

apparatus as that of the bat is a much greater change than that from the common to the flying squirrel; but self-adaptation will account for this in a great degree; once the animal began to gain anything by flapping its membranes, the muscles used in doing so would strengthen and grow, in virtue of the law that every muscle strengthens and grows with use. There is no difficulty in believing that it would begin to flap its membranes as soon as it became useful to do so; if mere animal intelligence were not sufficient to originate such an instinct, it might begin in some spontaneous variation, much less strange than that in which the characteristic habit of the tumbler pigeon began. This is exactly the same as the question how animals with legs first learned to creep and to walk.

Self-adaptation and natural selection co-operating.

I agree with Darwin in believing that natural selection can produce changes which self-adaptation has no tendency to produce. But the process of self-adaptation, in whatever direction it is going on, will be so furthered and assisted by natural selection that the effects of the two will be impossible to separate. Self-adaptation gradually adapts organisms to their mode of life; natural selection destroys those which are least adapted; and it is obvious that when these factors are both in operation, they will work to the same result.

But is this explanation of the probable origin of the bat's or the flying lemur's wing satisfactory? Does it explain all the facts? I greatly doubt whether it does. I do not see how it will account for the fact that in the

Extensor muscle of wing of flying lemur.

flying lemur "the flank membrane is also furnished with an extensor muscle."[1] I do not think that any clear evidence has been brought, proving that either self-adaptation or spontaneous variation will suffice to produce a new muscle. But there are so many instances of organs

[1] See quotation from Darwin above.

which appeared to be quite peculiar, proving to be really homologous with organs in other species,[1] that I attach little weight to such an objection. I only mention it as an unsolved difficulty, without implying that it is an insoluble one. If the extensor muscle of the flying lemur's wing-membrane can, for instance, be shown to be homologous with some muscle in any other lemur, similar to those muscles by means of which the horse shakes his skin when tickled, it will be safe to infer that the two muscles are the same in origin, but modified for different work by habitual self-adaptation.

These wing-membranes—at least in what I believe to be their initial stage—are, as I have already remarked, themselves very simple organs, and also not in very close correlation with any other organs. But will natural selec- *Will natural selection account for closely correlated, or complex organs?* tion account for changes in organs which are so closely correlated together that no variation in one of them can be of any use to the organism unless it is accompanied by corresponding variations in all the rest? And will it account for the complex perfection of an organ like the eye or the ear, consisting of many closely correlated parts? On this subject H. Spencer says :—" The co-operative parts *Quotation from Herbert Spencer.* must vary together, otherwise variation will be detrimental. A stronger muscle must have a stronger bone to resist its contractions; must have stronger correlated muscles and ligaments to secure the neighbouring articulations; must have larger blood-vessels to bring it supplies; must have a more massive nerve to bring it stimulus, and some extra development of a nervous centre to supply this extra stimulus. The question arises then,—does spontaneous variation occur simultaneously in all these co-operative parts? Have we any reason to think that they spontaneously increase or decrease together? The assumption that they do seems to me untenable."[2] He goes on to show that if, for instance, the horns of a deer grow larger through

---

[1] See especially the facts stated in the preceding chapter about respiratory organs, and those in the chapter on Comparative Morphology on the homological relations of the limbs of Vertebrates.

[2] Principles of Biology, p. 453.

spontaneous variation, and this, being advantageous to the deer by increasing its fighting power, is perpetuated by natural selection, it will be necessary for the muscles and bones of the neck and fore-legs to acquire increased strength in order to carry the increased weight of the horns; and it will be almost infinitely improbable that the necessary changes should all occur together from spontaneous variation only. But I agree with H. Spencer, that such cases present no difficulty whatever. Let natural selection increase the size of the horns, and self-adaptation will produce the corresponding increase of strength in the muscles and bones.

Com-
plexities
of the eye
and the
ear

But what are we to say of the complexities of the eye and the ear? We have seen that they cannot have been produced by self-adaptation. Neither the action of light on the eye, nor any action of the eye itself, can have any tendency whatever to produce the deposit of black pigment that absorbs the stray rays, nor to shape the transparent humours into lenses, nor to form the iris and its nervous connexions. And the hypothesis of natural selection appears equally inapplicable. In speaking of the flying squirrel, I have shown that I think natural selection adequate to account for any amount of im-

not due to
natural
selection.

provement in a simple organ; but it does not follow that it will account for any improvement in a complex organ. H. Spencer's reasoning to show that the increase in the strength of an animal's neck and fore-legs at the very time when this is needed in order to carry heavier horns cannot be a result of mere spontaneous variation, applies, I think, with much greater force to so complex an organ as the

Darwin on
the sim-
plest eyes.

eye. "The simplest organ which can be called an eye consists of an optic nerve, surrounded by pigment cells, covered with translucent skin, but without any lens or other refractive body. We may, however, according to M. Jourdain, descend even a step lower, and find aggregations of pigment cells, apparently serving as an organ of vision, but which rest merely on sarcodic tissue not furnished with any nerve." [1] Darwin remarks " that, as some

[1] Darwin's Origin of Species, p. 216.

of the lowest organisms, in which nerves cannot be detected, are known to be sensitive to light, it does not appear improbable that certain elements in their tissues or sarcode should have become aggregated and developed into nerves endowed with special sensibility to its action."[1] This is in accordance with all that we know of the process of development; and I believe as firmly as Darwin can do that the eyes of the highest animals, like everything else in the organic creation, have been brought to their present perfection by adding together a number of small improvements, continued through an immense number of generations. But it does not follow that these improvements, even though almost infinitely small, can be due to natural selection among spontaneous variations. The higher the organization, whether of an entire organism or of a single organ, the greater is the number of the parts that co-operate, and the more perfect is their co-operation; and consequently, the more necessity there is for corresponding variations to take place in all the co-operating parts at once, and the more useless will be any variation whatever, unless it is accompanied by corresponding Natural variations in the co-operating parts; while it is obvious selection that the greater the number of variations which are needed in order to effect an improvement, the less will be the organization probability of their all occurring at once. It is no reply tion. to this to say, what is no doubt abstractly true, that whatever is possible becomes probable, if only time enough be allowed. There are improbabilities so great that the Improba- common sense of mankind treats them as impossibilities. equal to It is not, for instance, in the strictest sense of the word, impossibility. impossible that a poem or a mathematical proposition should be obtained by the process of shaking letters out of a box; but it is improbable to a degree that cannot be distinguished from impossibility; and the improbability of obtaining an improvement in an organ by means of several spontaneous variations all occurring together is an improbability of the same kind.[2] It is, of course, out of the question to find numerical data on such subjects, but the

---

[1] Origin of Species, p. 215.　　　[2] See Note at end of chapter.

reasoning admits of algebraic statement. If we suppose
that any single variation occurs on the average once in
m times, the probability of that variation occurring in
any individual will be

$$\frac{1}{m};$$

and suppose that x variations must concur in order to
make an improvement, then the probability of the neces-
sary variations all occurring together will be

$$\frac{1}{m^x}.$$

Now suppose, what I think is a moderate supposition, that
the value of m is 1000, and the value of x is 10 : then

$$\frac{1}{m^x} = \frac{1}{1000^{10}} = \frac{1}{10^{30}}.$$

To many readers these numbers will have no meaning.
But it will speak to the understanding, though it will
baffle the imagination, to say that if these suppositions are
true, the probability against the concurrence of such vari-
ations as would constitute an improvement is expressed by
a number which is about ten thousand times as great as
the number of waves of light that have fallen on the earth
since historical time began.[1] And it is to be further
observed, that no improvement will give its possessor a
certainty of surviving and leaving offspring, but only an
extra chance, the value of which it is quite impossible to
estimate.[2]

Of course this argument falls to the ground if it can be
shown that it is not necessary for more than one variation
to take place at the same time in order to constitute an
improvement. But I think this is inconsistent with the
unquestionable fact, on which I have already insisted, that
in the highest organization there are both the greatest

[1] In 6,000 years there are, making no correction for leap years,
$189,216 \times 10^6$ seconds. In one second there are 535×10^{12} undulations of
yellow light. The product of these two numbers is $101,230,560 \times 10^{18}$, or
not much more than 10^{26}, which is the ten-thousandth of 10^{30}.

[2] See Note at end of chapter.

number of co-operating parts, and the closest co-operation between the parts.[1] It is to be observed, that the foregoing argument is greatly understated. I have spoken only of the co-operation of parts in one organ. But in nature we have also to do with the co-operation of organs in one organism; and most organs are complex; so that there must be co-operation of many organs, each of them consisting of many parts. In some cases, no doubt, the principle of self-adaptation will account for one part becoming adapted to the rest, as we have seen in speaking of the deer's horns and the bat's wing-muscles; but this will not be always the case. What greatly increases the difficulty of supposing that the eye can have been formed by natural selection is, that it has been formed not on one, but on three distinct lines of descent. Well-developed eyes are found in the higher orders of Annulosa, Mollusca, and Vertebrata. We need not now discuss the question, whether these three groups are descended from a common ancestor; if they are, that ancestor must have been, in all probability, of too low an organization to have eyes. We may infer this from the facts that the lowest known vertebrate, the amphioxus, has only rudimentary eyes,[2] and the lower Mollusca and Annulosa have none. The eye must consequently have been separately perfected in those three groups. It is a fact of the same class, that the Cephalopoda (cuttle-fish and nautilus), which are the highest of the Mollusca, resemble the Vertebrata not only in the general higher development of the nervous system and of the eyes, but in the special and very remarkable

Co-opera-tion of parts in an organ, and of organs in an organism.

The eye has been formed on three separate lines of descent.

Skulls of Cephalo-poda and of Vertebrata.

---

[1] H. Spencer has given the emphasis to this argument that it deserves (see the extract above). Yet he says, though without offering any proof, that the complexities of the sensory organs must be the result of natural selection. I cannot avoid thinking that he has been biassed by a determination to assign a *physical* cause, such as either self-adaptation or natural selection, for all biological facts, to the exclusion of intelligence. (See his Principles of Biology, vol. ii. p. 307.)

[2] " An eye, such as exists in the fish called the lancelet (amphioxus), which is so simple that it consists only of a fold-like sac of skin, lined with pigment and furnished with a nerve, but destitute of any other apparatus, being merely covered by transparent membrane." (Darwin's Origin of Species, p. 218.)

character of having a skull formed of cartilaginous plates,
to protect the cephalic ganglia; and yet there is no true
affinity between the Cephalopoda and the Vertebrata,
by the test either of morphological anatomy, or of deve-
lopment, or of a gradation of intermediate forms: so that
the skulls of the two groups, like their eyes, must have
been formed separately. Exactly the same remarks will
apply to the fact, that both the Vertebrata and the higher

Striated
muscular
fibre in
Annulosa
and in
Verte-
brata.

Annulosa have their voluntary muscles formed of striated
fibre, while the involuntary muscles of those groups, and
all the muscles of the Mollusca, are non-striated.[1] If the
Vertebrata and the Annulosa have been descended from a
common ancestor, that ancestor must have been far too low
in the scale to possess striated muscle; and consequently
that tissue must have been formed in those two groups in-
dependently. The origin of tissue, however, is so totally
unknown, that no argument drawn from it can be of much
weight. I have already admitted that I do not see any
absurdity in the idea of the muscular, and perhaps even
the nervous tissues being, in some way, originally produced
by a process of self-adaptation.

Sponta-
neous
variation
and
natural
selection
is a pro-
cess of
blind trial,

Natural selection among spontaneous variations may be
described, without a metaphor, as a process of experiment
by mere *blind trial*, and preserving the results of the suc-
cessful experiments, while the failures are destroyed and
forgotten. I do not deny that great results have been ob-
tained in this way. Such has been the case in some
chemical arts; above all, I believe, in photography; and it
is by such a process of blind experimenting, without any
acoustic theory to guide the experiments, that musical in-
struments have attained to their present high degree of
perfection. But this method is applicable only to cases
where the process of experimenting is comparatively
simple. Were it necessary for ten different experiments at

and in-
applicable
to complex
conditions.

once to be successful, in order that any result at all might
be obtained, such a method would be totally inapplicable;
the improbability of success would be an improbability of

[1] Carpenter's Comparative Physiology, p. 442.

the same kind (to recur to a former illustration) as that of obtaining a poem by shaking letters at random out of a box.

I conclude from these facts and reasonings, that the facts Summary. of organization may be accounted for in part by the direct action of external inorganic forces on the organism; in part by the action of the organism itself, producing self-adaptation; and in part by natural selection among spontaneous variations: but that in addition to, and in co-operation with, all these, there must be a principle of Organizing Intelligence. I shall defer the further consideration of the bearings of this conclusion to a future chapter, and shall end this with some observations on that very remarkable class of adaptations known as Imitative Resemblances.

Many birds, insects, and other animals have colours re- Imitative sembling those of the objects among which they live. colouring The purpose of this, beyond doubt, is protection against enemies: but what is the cause? Natural selection is the most obvious cause to assign, and in many cases it is probably quite adequate :—those individuals which were coloured like the objects among which they lived, escaped their enemies oftener than the ones not so favoured, and consequently survived and bequeathed their colouring. This view is supported by the fact that imitative colouring is worn by no birds except those which inhabit exposed in birds, places, where they would be in danger from birds of prey.[1] But this cannot be the purpose of the white colour of the Polar bear, which has no enemies, at least on land; its in the white clothing must have been given to it for warmth, as bear, white substances are those which radiate heat the slowest. Natural selection, however, will apply equally well to this case ; and if all cases of adaptive colouring were *single*, I should think this explanation would account for them all. But they are not all single ; there is the remarkable double and in the fact of some animals, of which the ermine is the best-known ermine.

[1] This is stated by the Duke of Argyll in "The Reign of Law."

instance, having a white covering in the winter, and one of
another colour in the summer.   I cannot think that this is
a result of natural selection among spontaneous variations,
because I cannot think that it could ever arise as a spon-
taneous variation; I think it must be in some way due,
fanciful as the notion may appear, to an action of the light
reflected on the animal from the surfaces among which it
lives.   The same is perhaps true (though this is a very
large concession to those who refer all the facts of organi-
zation to the action of inorganic forces)—the same, I say,
is perhaps true of the wonderful power possessed by
The cha- the chameleon and a few other animals, of assuming a
meleon. colour similar to that of the neighbouring surface, what-
ever that may chance to be.   These, in my view, can
scarcely be regarded as cases of *self*-adaptation: they
belong rather to the class of adaptations produced by the
direct action of external inorganic forces.

Mimicry.   But the fact of *mimicry*, as distinct from mere imitative
colouring, can, I think, be accounted for by natural selec-
tion, and by natural selection only.   Mr. Bates, the author
Quotation of "The Naturalist on the Amazons," has shown "that in
from
Darwin. a district where, for instance, an ithomia abounds in gaudy
Mr. Bates swarms, another butterfly, namely a leptalis, will often be
on mimic- found mingled in the same flock, so like the ithomia in
ry among
butterflies. every shade and stripe of colour, and even in the shape of
its wings, that Mr. Bates, with his eyes sharpened by col-
lecting during eleven years, was, though always on his
guard, continually deceived.   When the mockers and the
mocked are caught and compared, they are found to be
totally different in essential structure, and to belong not
only to distinct genera, but often to distinct families.   If
this mimicry had occurred in only one or two instances, it
might have been passed over as a strange coincidence.
But travel a hundred miles, more or less, from a district
where one leptalis imitates one ithomia, and a distinct
mocker and mocked, equally close in their resemblance,
will be found.   Altogether no less than ten genera are
enumerated, which include species that imitate other
butterflies.   The mockers and mocked always inhabit the

same region; we never find an imitator living remote from
the form which it counterfeits. The mockers are almost
invariably rare insects; the mocked in almost every case
abound in swarms. In the same district in which a species
of leptalis closely imitates an ithomia, there are sometimes
other lepidoptera mimicking the same ithomia; so that in
the same place, species of three genera of butterflies and
even moths may be found, all closely resembling a species
of a fourth genus. It deserves especial notice, that many
of the mimicking forms of the leptalis, as well as of the
mimicked forms, can be shown, by a graduated series, to
be merely varieties of the same species; whilst others are
undoubtedly distinct species. But why, it may be asked,
are certain forms treated as the mimicked, and the others
as the mimickers? Mr. Bates satisfactorily answers this
question, by showing that the form which is imitated
keeps the usual dress of the group to which it belongs,
whilst the counterfeiters have changed their dress, and do
not resemble their nearest allies." [1]

The purpose of mimicry is the protection of the *Its pur-*
mimickers. The species which they mimic, probably in *pose is protection.*
consequence of some odour that they emit, are not preyed
on by birds; and of course it is a protection to the butter-
flies which do not emit any such odour, to be mistaken for
those which do. The mimicking forms have no doubt *Its cause*
been produced by the survival, through successive genera- *is natural selection.*
tions, of those individuals belonging to defenceless species,
which most nearly resembled the kinds that have natural
means of protection. For the same reason, insects that
sting are never known to mimic others, though others
sometimes mimic them. [2]

---

[1] Darwin's Origin of Species, p. 503.   [2] Ibid. p. 506.

NOTE.

FORMATION OF COMPLEX ORGANS.

In answer to the objection that selection is inadequate to produce a co-ordinated structure of many parts, Darwin [1] points to the instance of the greyhound, all the parts of which are together "adapted for extreme fleetness, and the running down of weak prey;" yet the greyhound has been formed by selection; and the most competent selectors do not attempt to obtain all kinds of excellence at once, but try for one point at a time.[2] This instance is conclusive as to the correlation of characters, each of which may vary a little without necessitating variation in the rest. But I do not think it will apply to such an organ as the eye. On this subject Darwin says :[3]—

Grey-
hound.

"A writer has recently maintained that 'it is probably no exaggeration to suppose that, in order to improve such an organ as the eye at all, it must be improved in ten different ways at once. And the improbability of any complex organ being improved and brought to perfection in any such way, is an improbability of the same kind and degree as that of producing a poem or a mathematical demonstration by throwing letters at random on a table.'[4] If the eye were to be abruptly and

[1] Variation under Domestication, vol. ii. p. 221.

[2] "The excellence of one sub-variety (of pigeon), the Almond Tumbler, lies in the plumage, carriage, head, beak, and eye ; but it is too presumptuous in the beginner to try for all these points." The great judge above quoted (J. M. Eaton) says :—" There are some young fanciers who are over-covetous, and go for all the above five properties at once : they have their reward by getting nothing." (Variation under Domestication, vol. ii. p. 198.) Though these remarks are quoted of pigeons, Darwin evidently means them to apply to the improvement of the breeds of all animals. Compare what he says in p. 221 : " From what we know of the method which different men follow in improving their stock—some chiefly attending to one point, others to another point, others again correcting defects by crosses, and so forth."

[3] Variation under Domestication, vol. ii. p. 222.

[4] Darwin here quotes from my opening address to the Belfast Natural History Society, reported in the *Northern Whig*, Nov. 19, 1866.

greatly modified, no doubt many parts would have to be simultaneously altered, in order that the organ should remain serviceable. But is this the case with smaller changes ?" He then speaks of the changes that would be needed in order to adapt the eye of a diurnal species for a nocturnal life—a case which presents no great difficulty; and afterwards says :—" Amphibious animals, which are enabled to see both in the water and in the air, require and possess, as M. Plateau has shown, eyes constructed on the following plan : 'The cornea is always flat, or at least much flattened in front of the crystalline and over a space equal to the diameter of that lens,[1] while the lateral portions may be much curved.' The crystalline is very nearly a sphere, and the humours have nearly the same density as water. Now, as a terrestrial animal became more and more aquatic in its habits, very slight changes, first in the curvature of the cornea or crystalline, and then in the density of the humours, or conversely, might successively occur, and would be advantageous to the animal whilst under water, without serious detriment to its power of vision in the air."

Eyes of amphibious animals.

I confess I do not see much force in this argument. The subject is most intricate, but I know of no reason for thinking it possible that any apparatus consisting of lenses can be improved by any method whatever, unless the alterations in the density and the curvature are perfectly simultaneous ; and the probability against this taking place by mere spontaneous variation is practically infinite.

---

[1] The purpose of the flat cornea is evidently to produce as little difference as possible in the way in which the rays of light enter the eye from air and from water.

GENERAL REMARKS ON THE DEVELOPMENT OF SPECIES.

IN giving a brief summary of the argument on the origin of species, it is best to begin by repeating, that the origin of life is a distinct question. We have every reason

Origin of life in Creative Power.

to believe that life, like matter, has had its origin in the direct action of Creative Power. Accepting, then, the facts of life, with the laws of habit and variation, as primary data, the question is, how particular organic *structures*, and particular organic *species*, have come into existence.

Let us take the question of the origin of species first, as indeed it includes the other. Only two answers to this

Only two theories are possible as to the origin of species:

question appear to be possible. Either every species (with of course great indefiniteness as to the question what are in point of fact real and distinct species),—either every

separate creations, or development.

species, I say, has been separately created, or all species, both animal and vegetable, have been derived, by descent with modification, from one, or at most a few, germs that were originally vitalized by Creative Power. So long as the world was believed to be only a few days older than man, the theory of separate creations was necessarily

Question raised by geological discovery.

accepted. But when geological time was found to be indefinitely long, and when geology further disclosed the fact of a succession of species, the one set displacing the other and succeeding to it throughout geological time, the

Difficulties of development theory partly are probably insoluble,

question of the possibility of a change of species through descent was immediately raised. Such an hypothesis is no doubt surrounded with difficulties; or, it would be more correct to say, such an hypothesis raises a vast number of questions, most of which are not yet solved, and may pro-

bably remain ever unsolved. But all that we have learned, but they lessen with the advance of knowledge.
of the variability of form and function in organisms, tends
to diminish the difficulties of this hypothesis; while all
that we have learned concerning the facts of development,
embryology, morphology, and classification, tends to in-
crease its probability; and that probability is, as I think,
raised to the rank of a certainty by the discovery of rudi-
mentary and useless structures, both in mature and in
embryonic forms.

It appears to be a prevalent notion, that, whatever may
be hereafter concluded on as true, the presumption is at
present in favour of the theory of separate creations, and
will continue to be so until the argument is closed. I
cannot admit this; I think that it has no logical foundation No pre-sumption against the develop-ment theory.
whatever, and that it owes the force it has in men's minds
merely to the theory of separate creations being familiar;
while the theory of the origin of species by descent with
modification (or, briefly, the development theory) is still
comparatively strange. It is not to be hoped that the
difficulties of the development theory can be cleared up
at once, or that they can be fully cleared up at all. The
evidence is too scanty, and the experimental method,
which has created the sciences of physics and chemistry, is
scarcely applicable here. But the ordinary objections to
the development theory are utterly futile. It is said that Argu-ments from ex-perience against it
we have never seen a new species come into existence by
descent. This is scarcely true, for many races of plants
and animals have come into existence under domestication,
which it is nearly if not quite impossible to distinguish
from true species.[1] But it is quite true that we have never
seen any such change as the descent of a bird from a
reptile would be; and yet the birds and the reptiles are
both vertebrates, and must, therefore, on the development
theory, be descended either the one class from the other, or
both from a common origin. It is true, I say, that such a
change is quite out of our experience; but the separate are worth-less.
and special creation of any organic form out of dust, or out
of nothing, is equally outside of our experience, and far

[1] See Note at end of chapter.

more remote from it ; for we have experience of the origin of races by descent with modifications, though very small modifications, but we have no experience at all of the origin of

The argument from experience is in its favour.

a race by special creation. I believe this kind of argument from direct experience, in the narrowest sense of the word experience, is good for very little ; but, such as it is, it is in favour of the development theory, and not against it.

Difficulties about man.

This is the place for referring to those difficulties of the development theory which appear to be keenly felt by many, in connexion with the origin of man.

Development theory applicable to man.

Man is developed, like all other organisms, out of a minute structureless germ, which cannot by itself be distinguished from that which will develop into the form of any other species. Man is an air-breathing Vertebrate; I have brought forward what I believe to be conclusive proofs that all air-breathing Vertebrates have been descended from fishes; and if these arguments are good for other species, they are good for man also. Man is closely allied in his physical structure to the apes; the best authorities appear to be agreed with Professor Huxley, that

Man's brain not essentially unlike the ape's.

there is no difference, either in the brain or in any other part of the body, between man and the apes that can be regarded as in any way fundamental. The superiority of man's mental powers to those of the highest animal is no doubt so great that it may be regarded as infinite; but we have seen that motor and mental characters are so variable in comparison with formative ones, that they are no index whatever to the affinities of a species. As a question of biological science, consequently, I see no reason to doubt that man, like other species, has been developed out of lower forms.

The repugnance to this belief rests on the notion that where there is gradual change there can be no fundamental change of nature ; and, consequently, that if man has been developed out of an ape, he is still essentially an ape. Now, without entering on any logical or metaphysical discussion, I meet this argument by saying that such is not the fact: I say that a gradual change by development may be a fundamental change. The logical, or meta-

physical, difficulty of conceiving how such a being as man
can be descended from an ape, the ape from a fish, and
the fish from a Protozoon, is paralleled in the life of every
human being, by the facts that the child, before it learns
to speak, appears to have no higher mental nature than
that of a dog; that for some considerable time after birth
it appears to have no mental nature at all; and that at
the first moment of its conception it is not only without
mental nature, but without any higher organic nature than
that of a Protozoon. The development of the individual
is in the highest degree mysterious; but the mystery is
only repeated, and the difficulty is not increased, if it is
true, as I believe it is, that the development of the indi-
vidual, from the structureless germ up to the man, has had
its parallel in the development of the race. The relation
of man's spiritual nature to his animal nature is, no doubt,
one of the greatest of all mysteries; but the relation of life
to matter is equally mysterious, though it is a lower kind
of mystery. No merely physical science can elucidate a
spiritual mystery like this; but, in my opinion, the dis-
covery that man's brain has no anatomical superiority to
that of the highest apes, from which his mental superiority
could possibly be guessed, is so far from lending support
to a materialistic view of our spiritual nature, that it tends
to cut away the ground from under any materialistic
argument. I do not see any improbability in the belief
that the same Creative Power which at the beginning
created matter, and afterwards gave it life, finally, when the
action of that life had developed the bodily frame and
the instinctive mental powers of man, completed the work
by breathing into man a breath of higher and spiritual life.

*The deve-
lopment
of man
from the
lowest
forms is
paralleled
in the life
of every
individual.*

*Man's
spiritual
nature
may be a
direct
result of
Creative
Power.*

The theory, or rather the law, of organic types has been
sometimes set up in opposition to the theory of develop-
ment. The notion of any opposition between them, how-
ever, is a pure misconception. By the law of types is
meant the fact, which has been stated at greater length in
the chapter on Morphology, that homologous parts are
found through vast numbers of species—as, for instance,

*The law of
organic
types*

through the whole vertebrate group; and that when a new
organ is needed—as, for instance, a wing instead of a leg—
the type is not radically altered, but modified in such a
way as to leave the same anatomical elements still dis-
cernible.   There are some who regard it as a sufficient
answer to the question of the origin of species, to say that
the Creator has laid down plans, or types, for the Verte-
brata, and for each of the other great groups, and then
modified the vertebrate type to suit the special modes of
life of the fish, the quadruped, and the bird; and the other
types in the same way.   Now, as a statement of fact, this
is perfectly true; but it is only a generalized statement of
explained fact—it is no explanation.   The development theory takes
by the
theory of up the question at this point, admits the law of types as
develop-   true, and shows why it is true; namely, that homological
ment.
resemblances are due to community of descent.   The deve-
lopment theory does for the multitudinous facts of mor-
phology, embryology, and classification, what Kepler's laws
did for the mass of facts previously known concerning the
planetary motions : it shows how they are to be referred
to simple and intelligible principles.   But Kepler's laws
left unanswered the question of the agency by which the
planetary motions were determined; and the development
The deve- theory, considered merely as such, leaves unanswered the
lopment
theory   question by what agency the development of species has
does not   been produced.   Any theory that will explain this will do
answer the
question   for the development theory what the Newtonian theory
of the   of gravitation has done for Kepler's laws.   Darwin
cause of
develop-   believes that he has discovered such a theory.   I regard
ment.   his theory as not false, but totally insufficient; partly
because, as I have shown at some length in the last
chapter, I do not believe it will in any degree explain
the more complex facts of organization ; partly because,
while it throws very great light on the variation of *forms*,
it throws little or none on the origin and variation of
tissues.

I have not yet considered the geological evidence on the
subject of the origin and succession of organic forms.   I

believe the geological evidence is too scanty and frag-
mentary to be of much value;[1] but what we have is cer-
tainly favourable to the belief that there has been, on the
whole, an advance in grade of organization during geolo-
gical time. Thus, reptiles have been superseded, to a great
extent, by warm-blooded animals; the great marine rep-
tiles have given place to whales and other Cetaceans, the
great land reptiles to Mammalia, and the Pterodactyles, or
flying reptiles, to birds. This, however, says nothing either
for or against the theory of natural selection among spon-
taneous variations as the principal cause of improvement.
But I think that, on the whole, geological evidence is
against that theory. Were it true—were natural selection
not only one cause of change, which it certainly is, but the
principal cause—improvement ought to take place most
rapidly in the classes where there is most variability, and
least fixity of form: in other words, selection ought to do
most where there are the most numerous and the greatest
variations to select from. Now, variability as between
individuals is greatest in the lowest classes: but this
does not cause the production of new species to go on
among them with any corresponding rapidity. Geologists,
on the contrary, appear to be agreed that old species
disappear, and new ones come to take their places, most
rapidly in the highest classes. I think this is an impor-
tant argument in favour of believing that advance in
development is due to some vital power which is most
energetic in the highest classes, and not to any mere
inorganic agency like natural selection.

margin notes: Geological evidence favours the belief in advance. Reptiles have given way to warm-blooded animals.

Geological argument against Darwin's theory.

Improvement goes on most rapidly in the highest classes.

   We have to account not only for the fact of improve-
ment, or, in other words, for advance in grade of organiza-
tion, but for the fact that improvement goes on in divergent
lines. The organic tree not only grows higher, but branches
out into classes. This, however, presents no difficulty, if
it is admitted, as the development theory requires, that if

margin note: Divergence of character.

   [1] See the chapter, in Darwin's Origin of Species, on the Imperfection of
the Geological Record; also "Illogical Geology," in the second volume
of Herbert Spencer's Essays.

time enough is allowed variation is perfectly indefinite in amount, at least within the limits of the same fundamental form. Isolation alone appears to produce change. If a small colony of any species whatever were to be isolated from its kind, it can scarcely be doubted that after some generations it would come to constitute a distinct variety. Such cases have occurred under domestication;[1] and they must have been of constant occurrence in nature whenever some of the individuals of a species have been isolated from the rest by the formation of mountain or sea barriers.

Effect of isolation in producing change.

But it is on the largest areas obviously that there will be the largest number of chances of favourable variations occurring ; and there consequently those species will be perfected which will be most successful in the " struggle for existence."[2]   Thus European and Asiatic species of plants are now overspreading Australia and New Zealand, while the Australian and New Zealand species, which have been introduced as garden plants, have little tendency to become wild in Europe. No doubt the most favourable state of things for the promotion of variation and advancement is that which geological conditions have produced,— constant, but generally slow changes in the conditions of life ; general severe competition, with many isolated areas in which it is less intense ; colonies frequently shut off from the parent stock, and left alone to vary or to remain unchanged ; and species which had been matured in separate regions suddenly brought into competition by the removal of barriers. Every geological change will tend to

The largest areas produce the most dominant species.

General effect of geological conditions.

[1] " Youatt gives an excellent illustration of the effects of a course of selection, which may be considered as unconsciously followed, in so far that the breeders could never have expected, or even have wished, to produce the result which ensued—namely, the production of two distinct strains. The two flocks of Leicester sheep kept by Mr. Buckley and Mr. Burgess, as Mr. Youatt remarks, 'have been purely bred from the original stock of Mr. Bakewell for upwards of fifty years. There is not a suspicion existing in the mind of any one at all acquainted with the subject, that the owner of either of them has deviated in any one instance from the pure blood of Mr. Bakewell's flock, and yet the difference between the sheep possessed by these two gentlemen is so great, that they have the appearance of being quite different varieties.'"   (Darwin's Origin of Species, p. 37.)

[2] Ibid. p. 119.

promote change of the living species in different ways :
by causing self-adaptation to the new conditions of life;
by directly stimulating variation, and by selecting those
variations which are best adapted to the new conditions.
What I wish now to insist on is, that all this will neces-
sarily produce "divergence of character;" for the new
influences will most probably act on only part of the indi-
viduals of a species, and among those which do come under
the new influences it is probable that different variations
will be adapted to different habits of life, and will be formed
by hereditary habit and natural selection into permanent
varieties or new species. Thus the constant tendency of
change will be to produce new varieties; and it appears
impossible that any retrograde change can reverse this,
or that it can be undone by any cause except their
extinction. *Tendency of geological changes to constantly greater variation.*

It is to be remembered also that with any particular
variation other variations will probably be correlated; but
of the laws of such correlations we know nothing. *Correlation of variations.*

It can scarcely be doubted that the lowest organisms are
the most plastic, and consequently the most capable of
assuming organization of a new type. It is probably for
this reason that allied groups, as already remarked, are
generally united by their lowest, and not by their highest
members. In more technical language, the least differen-
tiated species have the greatest capacity for further dif-
ferentiation, and are capable of giving origin to widely
distinct groups above them. Thus, for instance, the lowest
air-breathing Vertebrates—the Batrachians—are allied not
with the highest, but with some of the lowest fishes. The
lowest fishes, on the development theory, have given origin
to the higher fishes on the one side, and to the air-breathing
Vertebrates on the other. But we cannot assert that this
is universally the case. The affinities of birds, I believe,
are rather with the higher than with the lower reptiles;
and the same is probably true of the mammalia. *Lowest organisms are most plastic.* *Classes are usually united by their lowest members.* *There may be exceptions to this.*

Any intelligent man who has taken the trouble of fol-
lowing my reasoning so far will very probably make these *Apparent inconsistencies of*

my argu-
ment.

two remarks—that I have first rejected natural selection among spontaneous variations as a complete theory of the origin of species, and afterwards gone on as if I thought it true; and that I treat intelligence as a *Deus ex machinâ,* explaining vital phenomena, so far as I can, by merely physical causation, referring them to the action of external agents, self-adaptation, and natural selection, and only calling intelligence in as a solution when the physical causes fail to account for the facts.

I shall reply to these two objections together. I believe, as I have more than once stated already (and I think I here state the universal belief of scientific men)—I believe,

Life does not super-sede, but works through the pro-perties of matter:

I say, that the action of life does not supersede the ordi-nary physical laws of causation—or, in other words, does not supersede the ordinary properties of matter—but that life produces its results of organization by guiding the action of causation, and by working through the ordinary properties of matter. So it is with intelligence.

so intelli-gence with un-intelligent forces.

As life works through the inorganic forces, so intelli-gence, I believe, works through the unintelligent forces. All the inorganic forces are unintelligent, and so, I believe, are the laws of habit and variation. The rela-

These relations are inex-plicable.

tion of life to the inorganic forces is totally inexplicable, and the relation of intelligence to the unintelligent forces is equally so; but the latter, though inexplicable, forms

We have mental ex-perience of the action of intelli-gence.

part of our mental experience. Our mental life is partly intelligent and partly merely habitual. The intelligent and voluntary powers of the mind, as I shall have to show in a future chapter, do not supersede the action of the habitual powers, but work through them; and it is, I believe, the same in our unconscious or bodily life. Self-adaptation takes place according to the laws of habit, and according to that remarkable physical law in virtue of which every part that has increased work thrown on it within the limits of what is good for its health, increases in size, in strength, and in general efficiency; but it appears to be universally admitted that there are many adaptations for which no mere blind habitual process of self-adaptation will account. Natural selection also is a

purely physical process, a case of purely physical causa-
tion ; but I have given reasons, which to my mind are
conclusive, against accepting natural selection as an
explanation of the complexities of organic structure. But
I believe that these physical agencies, self-adaptation and
natural selection, are what produce organization, and are Self-
the operative causes of progress in organization ; not, adaptation
is guided
however, acting alone, but under the guidance of intelli- by intelli-
gence. I believe that intelligence guides the process of gence.
self-adaptation, producing adaptations which no unintelli-
gent process could produce. I have no doubt the law of
natural selection is universally operative, in this sense, that
natural selection by "survival of the fittest" [1] in the
struggle for existence is the reason why new and improved
races, *when once formed,* supersede the old and unimproved
ones; but I have stated my reasons for believing that
spontaneous variation alone can never produce any com-
plex organization. I believe that intelligence determines Intelli-
those variations to occur together which are needed together. gence
determines
To return to a former instance :—If I am right, such an co-ope-
organ as the eye has been formed by a series of gradual rating
variations
successive improvements, in each of which those different to occur
together.
variations in the different parts of its complex structure
which are necessary to make one another useful have been
determined to occur together by the mysterious power of
unconscious organic intelligence. But every improvement,
when once made, has been preserved, perpetuated, and
multiplied by the action of natural selection.

I believe that organizing intelligence co-exists and co- Intelli-
operates with the unintelligent forces through all life; but gence is
most domi-
that intelligence is most completely dominant in the highest nant in the
highest
life. It is where intelligence is most completely dominant life.
that, as we have seen, organic progress is most rapid;
though there is least spontaneous variation among the
most highly organized forms, and consequently it is among
them that the least could be done by mere natural selec-
tion among unguided spontaneous variations.[2] And it is

[1] This expression is used in Spencer's Principles of Biology.
[2] See p. 333.

also where intelligence is most completely dominant that
we find those organs, such as the eye and the ear, of which
the purpose is the most evident and the most definite, and
which appear most completely beyond the power of any
merely physical causation to construct.   Purpose, as I
remarked early in this work, is most traceable where cause
is least so.

In the first chapter of the second volume I shall have
to consider what this organizing intelligence is; and this
will further open the question of the relation between the
unconscious life and the mind.

NOTE A.

THE OPERATION OF NATURAL SELECTION.

Why does
natural
selection
preserve
the
highest?

THE first question of an intelligent man when he first hears the
theory of the Origin of Species by means of natural selection
among spontaneous variations, will very probably be something
like this :—Granting its postulates, your theory no doubt ac-
counts for the origin of *different* species, one from the other, by
descent.   But the most important and conspicuous fact in com-
paring species and classes is not mere variation, but advance.
Granting that natural selection among spontaneous variations is
adequate to effect the transition from the Protozoa up to the
highest warm-blooded animals, the question still remains, why
the changes it effects are in this direction ?   Why does natural
selection, or " survival of the fittest," on the average and on the
whole, preserve those variations that constitute advance in
organization, and destroy the retrograde ones ?

Because
the highest
are most
efficient.

The answer to this is obvious, and is contained in what has
been said already.   The most highly organized beings have an
advantage over others in the struggle for existence.   Strength
of muscle, perfection of the organs of motion and prehension,
acuteness of the nerves of sense, perfection of the eye and ear,
and increased development of the nervous centres producing
mental intelligence,—all these constitute advance in grade of
organization, and all at the same time give their possessor an

increase of power to fight the battle of life, and consequently an increased chance of surviving and leaving offspring. This, however, is only an average result, not a uniform or constant one. For instance, if an animal becomes internally or externally Excep- parasitic on other animals, it will have little or no occasion for tions. acute senses or great motor power; its organs of sense and Retro- motion will consequently degenerate, and the whole organism, grade taken altogether, will undergo a retrograde change; while the change. great facility of obtaining abundant nourishment which its parasitic life affords, will cause the variation to be a favourable one, and it will be perpetuated. Such has no doubt been the Suctorial origin of the "suctorial parasites" on fishes and whales, into parasites. which many freely swimming crustacean larvæ are metamor- phosed. But such cases are distinctly exceptional. As a rule, natural selection will preserve only those variations which con- stitute an advance in organization, and the rest will perish.

Here another question arises, which Darwin has not seen, but which H. Spencer has seen and satisfactorily answered.[1] The ability of an individual, or of a species, to survive in the battle of life no doubt depends on its organization; and the chances Chance of are, on the whole, in favour of the highest organization. But leaving the probability of its not only surviving but leaving offspring, offspring does not depend on this exclusively; it depends partly on its deter- organization, but partly on its fecundity. Other things being mined by equal, the highest organization will have the best chance. But, fecundity. other things being equal, the greatest fecundity will have the best chance. The chance that any variety will have of being preserved by natural selection will be in a ratio compounded of its organization and its fecundity.

The advantage that fecundity gives to a species may be seen Rabbit by comparing the rabbit with the hare. The hare would pro- and hare. bably be by this time extinct in the cultivated parts of our country, were it not preserved, while the rabbit has no diffi- culty in maintaining its position; a difference which may be partly due to the burrowing habits of the latter, but much more, I think, to its great fecundity.

To resume the argument. Fecundity and high organization High do not in general accompany each other, but the reverse. The organiza-

---

[1] What follows is in substance taken from Spencer's Principles of Biology, Part VI., especially chapters ix. and xi. The algebraic statement of the reasoning is my own.

tion and
fecundity
are
opposed.

highest organisms have on the whole the least fecundity. Compare the comparatively small number of young produced by birds and Mammalia with the thousands of eggs produced by some fishes and many insects, and the countless germs of the

Bearing of
this law on
natural
selection.

lowest animals and plants. Might it not be expected, that whatever is gained in the chance of leaving offspring by advanced organization will on the average be lost by diminished fecundity; that the greater fecundity of the inferior types will give them as good a chance of leaving offspring as the superior ones ; and that the superior and the inferior species will thus be in the long run evenly matched in the battle of life, giving the superior ones no permanent advantage ?

This would be so if all other things were equal. But all other things do not remain equal. The advantage of any favourable variation to a race consists generally either in greater facility of obtaining food, or in greater facility of escaping enemies ; and either abundant food or tranquillity of life will tend to increase fecundity. So that advance in grade of organization, though it will entail diminished fecundity as its direct effect, will tend to counteract this effect in an indirect way, namely by placing the organism in external circumstances favourable to its fecundity.

In such a question, verification by observation or experiment is totally out of the question. But the above reasoning, considered merely as reasoning from what data we have, is, I think, sound and satisfactory. It may be well to put it into an algebraic form.

Algebraic
statement.

Call grade of organization x, and fecundity y. Suppose, what is approximately true, that the chance of surviving and leaving offspring is proportionate to their product xy; and suppose, what is also approximately true, that, other things being equal, the values of x and y are inversely as each other ; then, other things being equal, xy will be a constant quantity, and no increase in the value of x from any favourable variation will increase the chance of leaving offspring. Call now abundance of nutrition a. Within limits, the value of y, as already shown, will increase with that of a, and the value of a will increase with that of x ; so that any increase of the value of x from spontaneous variation will tend to increase that of y, and consequently of the product xy; while, on the contrary, no increase of the value of y will have any tendency to increase that of either x or xy.

NOTE B.

AT the time when the foregoing chapter was written, I was The
not aware of the fact mentioned by Mr. Lewes in an article on domestic
Darwin's theory in the *Fortnightly Review*, that the domestic Guinea-pig
and the wild Guinea pig are not fertile together. Mutual fer- do not
tility is the usually accepted test of identity of species; so that together.
by this test these two are distinct species.

THE RATE OF VARIATION.

Variation
is slow:

IT is a necessary result of any form of the develop-
ment theory, indeed I may say a part of it, that the
process of variation by which any great change in organic
forms has been effected has been extremely slow : so slow
as to be measurable only by geological time. Darwin
constantly insists on this.

Of course it is impossible to doubt that such a change
as that involved in the descent of warm-blooded animals
from fishes, or of winged insects from worms, must have
occupied immeasurably long geological ages. But Darwin
goes much further than this ; he thinks that all species
whatever have been formed by a process of variation not
more rapid than that by which, in most cases, our domestic

but I think
not so slow
as Darwin
maintains.

races have been, and are, improved. I am inclined here to
differ from Darwin. I think it most likely that, in many
cases, species have been formed at once by considerable

Possible
sudden
origin of
new
species.

variations ; variations not comparable to that which would
be necessary to derive an air-breathing animal from a
water-breathing one, but amounting to the sudden forma-
tion of new species and new genera.

Such has
occurred
under
domesti-
cation.

In this belief there is nothing inconsistent with the
laws of life. Variations, equal in magnitude to the pro-
duction of new species, do occur under domestication. I
have mentioned, in the chapter on the Laws of Variation, a

Poppy.

case of a new variety of the poppy appearing suddenly,
which had " a remarkable variation in its fruit, a crown

Datura
tatula.

of secondary capsules being added to the normal central
capsule :" and a similar case of the datura tatula, present-

ing a variety with smooth fruit instead of spinous.[1]   Here
are two cases of variations amounting to specific differ-
ences, which appeared suddenly, and were propagated by
seed: they are in fact cases of the production of new
species, not by gradual, but by sudden variation, and they
would be recognised as such if they had appeared in the
wild state.   The otter, or Ancon, sheep of North America Ancon
was also the result of a sudden variation; and the differ- sheep.
ence in the form of its skeleton from that of the common
sheep amounted to a specific if not a generic difference.
Thus we see that sudden as well as gradual variation may
give rise to what are really new species, both of plants
and animals.   It is true, these instances, and others that
could be mentioned,[2] have arisen under domestication;
but why may not the same have taken place in the
wild state?   Darwin thinks they do not: "Various
general reasons," he says, "could be assigned against such
a belief: for instance, without separation a single monstrous
variation would almost certainly be soon obliterated by
crossing."[3]   I think this difficulty is quite imaginary.   We
know that vegetable species and varieties usually propagate
their kind truly; and among animals, once a race has been
formed, the instinct of every race to unite with its own Instinct
kind will, in the wild state, prevent crossing.   Besides, will
prevent
even if they unite, it is by no means certain that their crossing.
union would produce a mixed race, having characters Crossing
intermediate between the two parent stocks.   When two might not
produce a
slightly different individuals unite, the offspring, no doubt, mixed race.
have on the average an intermediate character; and thus
it is that where free intercrossing is permitted, separate
breeds do not usually arise in the same country.   But this
is not always the case when the union is between indi-
viduals of very unlike races.   "When the Ancons (or

---

[1] P. 197.

[2] "It is certain that the Ancon and Manchamp breeds of sheep, and
almost certain that the niata cattle, turnspit and pug dogs, jumper and
frizzled fowls, short-faced tumbler pigeons, hook-billed ducks, &c. and
with plants a multitude of varieties, suddenly appeared in nearly the same
state as we now see them." (Darwin's Variation under Domestication,
vol. ii. p. 414.)   [3] Ibid.

otter sheep) are crossed with other breeds, the offspring, with rare exceptions, perfectly resemble either parent."[1] For these reasons, I think there is no improbability in sudden, as well as slow, variations occurring among organisms in the wild state ; though, as wild organisms are much less variable than domestic ones, they must occur much more rarely.[2] It may be true that we have no evidence of the origin of wild species in this way. But this is not a case in which negative evidence proves any-

Sudden origin of a wild race would not be discovered. thing. We have never witnessed the origin of a wild species by any process whatever ; and if a species were to come suddenly into being in the wild state, as the Ancon sheep did under domestication, how could we ascertain the fact ? If the first of a newly-begotten species were found, the fact of its discovery would tell nothing about its origin. Naturalists would register it as a very rare species, having been only once met with, but they would have no means of knowing whether it were the first or the last of its race.

Geological time too short for the theory of *slow* variation. I consequently think that sudden variation is not only possible, but probable. And I further doubt whether the development theory is tenable unless we admit it. I am inclined to think that geological time is too short for the evolution of the higher forms of life out of the lower by that accumulation of imperceptibly slow variations, to which alone Darwin ascribes the whole process.

This will surprise many readers. It is almost as start- ling now to be told that geological time is less than infinite, as it would have been a hundred years ago to be told that historical time was but a small fraction of the age of the earth. Nevertheless, the reasoning which has been briefly stated in the chapter on "the Motive Powers of the Universe," proves that the order of things on the earth **Age of the earth according to Sir W. Thomson.** must have had a beginning ; and Sir William Thomson has roughly estimated the past duration of the solar system in its present state at about five hundred millions

---

[1] Darwin's Variation under Domestication, vol. i. p. 100.

[2] "Sports" are extremely rare under nature, but far from rare under domestication. (Darwin's Origin of Species, p. 10.)

of years; previous to which time it was condensing out of
its original nebula. Of course this calculation does not
make the slightest pretension to precision, but all that is
needed for the present argument is the order of the mag-
nitude.[1] Five hundred millions of years is a period so
overpowering to the imagination, that it is no wonder if
most readers think it equivalent for all practical purposes
to eternity. I think, however, that for the present purpose
this is very doubtful.

Darwin justly mentions the greyhound as being equal *The grey-*
to any natural species in the perfect co-ordination of its *hound an*
artificial
parts, "all adapted for extreme fleetness and for running *species;*
down weak prey."[2] Yet it is really an artificial species,[3]
formed by long-continued selection under domestication;
and there is no reason to suppose that any of the varia-
tions which have been selected to form it have been
other than gradual and almost imperceptible. Suppose
that it has taken five hundred years to form the greyhound *produced*
out of his wild wolf-like ancestor: this is a mere guess, *in perhaps*
500 years,
but it gives the order of the magnitude. Now, we have *by slow*
seen that the past duration of the earth has been about *variation:*
five hundred millions of years, or only one million times
greater than this; yet during that period all those changes
have taken place by which the highest animal—let us say
the elephant—has been developed out of a Protozoon;
or, if we admit the hypothesis of a separate ancestor for
the vertebrate and for every other fundamentally distinct
form, during that period the elephant has been developed
out of the earliest and most lowly organized fish. Now, if
it takes five hundred years to obtain the present race of
greyhounds from a wolf-like ancestor by an accumulation
of slow variations, how long would it take to obtain an *how long*
would the
elephant from a Protozoon, or even from a tadpole-like *production*

---

[1] See the article on Darwin's theory, in the *North British Review* for
June 1867.

[2] Darwin on Variation under Domestication, vol. ii. p. 221.

[3] This expression will be objected to. But, as I have already stated, I
think Darwin, in his Origin of Species, has proved that the distinction
between species and variety is only one of degree.

of the highest forms from the lowest require, by the same process?

fish? Ought it not to take much more than a million times as long? I ought perhaps to repeat, that if accuracy of numerical statement here is unattainable, it is also unnecessary; what we have to compare is not the magnitudes themselves, but only the orders of the magnitudes. But the argument, as stated here, is much too favourable to the theory of none but imperceptibly slow variations; for it compares variation under domestication with variation in a state of nature, as if it were equally rapid in

Variation is slower among wild than tame races.

both. And this is not the case : on the contrary, we may say, without much risk of exaggeration, that variability is the rule among domesticated races, but the exception among wild ones. Wild races remain unchanged throughout whole geological ages, though, I have no doubt, they become variable under the influence of changes of habitat, climate, and food; when these changes take place, new varieties and new species, more suitable than the old ones to the new conditions of life, will be formed by the conjoint action of self-adaptation and natural selection. But, so long as variation takes place so slowly as not to produce new races at once (which in Darwin's opinion is always

How selection will act in the wild state.

the case in the wild state), the formation of distinct races in the same habitat will be prevented by intercrossing, and it will be impossible for the processes of change to do more than to modify *the whole race together,* so as to suit the new conditions of life.[1] This will not prevent the action of " natural selection among spontaneous variations," in giving origin to new species, but it must tend greatly to restrict its operation so long as the variations are so small as not to give origin at once to new species, or strongly marked races. ·The absence of mixtures of race in the wild state will tend to prevent variation, for, as we have seen, pure races are less variable than mixed ones.

[1] If some individuals of a race were so far to change their habits as not to be brought into contact with their kindred,—as, for instance, in the case of becoming nocturnal instead of diurnal,—they would, no doubt, give origin to a new race. But such a change of habit comes to the same thing as a change of country.

Thus there will be less variation in the wild state than in the domestic; and such variations as occur will be much less likely to be kept separate so as to produce modified races. For, as we have seen, the improvement of domestic breeds depends altogether on separation, and would be impossible if the animals were permitted freely to obey their instincts as to breeding. It is true that instinct tends to keep *well-established* breeds distinct, but this is not the case when they are only beginning to diverge.

To recapitulate the foregoing argument:

Geological time is only about a million, or a few million, Summary. times as long as the period needed to form what is really a new species by the accumulation of small variations under domestication.

Variation goes on much less rapidly in the wild than in the domestic state, and favourable variations, when they occur, are much less likely to be so preserved as to produce a modified race. We shall probably be greatly within the mark if we assume that variation is ten times less rapid in the wild state than in the domestic, and that the chance of any favourable variation being so preserved as permanently to modify the race is ten times less. If these numbers are correct, then the efficiency of selection among *small* spontaneous variations in producing new races is one hundred times as great under domestication as in the state of nature. If this is so, then five hundred millions of years of variation and selection under nature are equivalent to only five millions under domestication. And if it takes five hundred years, or anything approaching to that period, to form a race like the greyhound out of a wild dog, it can scarcely be maintained that five millions of years of change at the same rate would suffice to form an elephant out of a fish. Five millions are only ten thousand times five hundred, and the proportion between those two changes is certainly measurable by no such number as ten thousand.

For these reasons, I believe there must have been sudden variations, amounting to the origin of new species all at once; not widely different in any case, perhaps, from the

old ones, but sufficiently different either not to mix with others, or to preserve their distinctness (like the Ancon sheep) in spite of intercrossing.

How far I agree with Darwin.   It may, perhaps, be asked whether I am after all a follower of Darwin or not.   This question cannot be answered by a mere yes or no.

I agree with the theory of which Darwin is not the founder but the best known and most original exponent, that all organic species have been descended from one or a few germs.

I believe that Darwin has done most important service to science by pointing out the importance of natural selection among spontaneous variations, as a cause of organic progress.   But I do not agree with him that it is almost the only cause.

I believe that geological time is too short to admit of the progress that has taken place, unless variation is a much more rapid process than Darwin admits.

I believe (as stated in the preceding chapter) that the facts of variability being greatest in the lowest organisms, while progress has been most rapid among the higher ones, shows that there is something in organic progress which mere natural selection among spontaneous variations will not account for.

Finally, I believe this something is that Organizing Intelligence which guides the action of the inorganic forces, and forms structures which neither natural selection nor any other unintelligent agency could form.

NOTE.

I FIND that, taking Sir William Thomson as my authority, I have greatly understated the argument of the foregoing chapter. I quote the concluding paragraph of his paper on Geological Time, in the *Transactions of the Geological Society of Glasgow*, vol. iii. :—

"When finally we consider underground temperature, we find ourselves driven to the conclusion that the existing state of things on the earth, life on the earth, all geological history showing continuity of life, must be limited within some such period of past time as *one* hundred million years."

END OF VOL. I.